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Unconventional Monetary Policy – Theoretical Foundations, Transmission Mechanisms and Policy Implications

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Preface

This thesis was written during my time as a research assistant at the Institute of Economics at the University of Hohenheim, Germany, and was accepted as a dissertation in January 2018. While working on this project I received indispensable support from various people to whom I would like to express my gratitude.

First and foremost, I would like to thank my supervisor Prof. Dr. Peter Spahn for his continuous support and encouragement. At his chair, he has always offered a very open and enjoyable working environment and I have benefited tremendously from the enlightening discussions we carried out about all sorts of topics. Many insights about monetary economics that I gained from these discussions found its way in this dissertation.

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Stuttgart,
March 2018 *Benjamin Schmidt*

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1. Introduction

"Well, the problem with QE is that it works in practice, but it doesn't work in theory."
— Ben Bernanke (2014)

1.1. Motivation and Objectives

The financial crisis of 2007-09 caused a sharp contraction in inflation and economic activity in almost any advanced economy. As a consequence, central banks around the globe adjusted their operating frameworks and initiated a series of aggressive interest rate cuts, but the scope for further conventional stimuli was soon exhausted by the effective lower bound on short-term nominal rates. Then, in September 2008, as the crisis intensified after the bankruptcy of the US investment bank Lehman Brothers, central banks started to expand their balance sheets at an unprecedented scale – either through large-scale asset purchases (QE), or through ample liquidity provisions against a broad set of collateral.

Interestingly, however, the effective use of central bank balance sheets stands in stark contrast to the pre-crisis consensus about the relevance of such measures. By abstracting from financial frictions, standard macroeconomic models predict that, even at the zero lower bound of the nominal policy rate, outright purchases of long-term government bonds have no direct impact on term premia (Woodford, 2010; Cúrdia and Woodford, 2011). In fact, since the 1980s, the scientific breakthrough of rational expectations models associated with *New Classical Macroeconomics* has resulted in quasi complete neglect of balance sheet effects. Instead, the *management of expectations* took the center stage in the scientific debate (Woodford, 2005a; cf. Woodford, 2005b). With respect to monetary economics, the widely adopted *New Keynesian model* (NKM) led to an exclusive focus on the short-term policy rate, while the ability of monetary policy to affect aggregate expenditure rested on the premise to influence market expectations about the future path of that rate.

Against this background, financial market imperfections and the role of balance sheet effects were neglected by most macroeconomic benchmark models, which included such curious assumptions as *Ricardian equivalence* (Barro, 1974), *Wallace neutrality* (Wallace, 1981; Eggertsson and Woodford, 2003) or the *Modigliani-Miller theorem* (Modigliani and Miller, 1958).

Under the guise of these neutrality assumptions, the respective models challenged earlier insights from economic theory, which had emphasized the role of market imperfections for the effectiveness of monetary policy. However, even more astonishing seems the fact that contemporaneous advances in microeconomic theory, which demonstrated various imperfections due to principal agent problems, were largely ignored in macroeconomic models. Based on these drawbacks, Hahn and Solow criticized the New Classical paradigm already in 1995 by noting that "[i]n a decade that has seen vast progress in our study of asymmetric information, 'missing markets,' contracts, strategic interaction, and much else precisely because those aspects are regarded as real phenomena that require analysis, macroeconomics has ignored them all" (Hahn and Solow, 1995, p. 2; cf. Turner, 2014).

Thus, one aim of this thesis is to elaborate on the theoretical foundations for the effectiveness of *unconventional* monetary policies. This is done by contrasting the pre-crisis consensus with more recent advances in macroeconomic theory. Secondly, I investigate the various transmission channels of QE and show that asset purchases, conditional on the state of the financial system, can have large effects on financial market prices. Thirdly, I assess the empirical evidence concerning the financial and macroeconomic effectiveness of unconventional monetary policies. In this context, the evidence suggests that the macroeconomic effects are generally smaller than their financial market effects, even though unconventional policies may also have negative repercussions on financial stability – especially if a protracted period of low interest rates triggers excessive risk-taking by leveraged investors. Nevertheless, and despite those potentially negative consequences, the theoretical premises about the effectiveness of unconventional policies stand up to empirical scrutiny. Thus, by referring to Bernanke, a central message of this thesis can be summarized as: QE works in practice, but it *also* works in theory!

1.2. Plan of the Book

The financial crisis of 2007-09 can be divided into a ’pre-Lehman’ and a ’post-Lehman’ episode. The ’pre-Lehman’ episode lasted from August 2007 to September 2008 and was largely confined to distressed European and US money markets. In comparison, the ’post-Lehman’ episode was characterized by a global economic slump, deflationary risks, and policy rates at the effective lower bound in most advanced and many emerging economies. Accordingly, part I of this thesis starts with the monetary policy response to the ’pre-Lehman’ turmoil on interbank markets, while part II addresses unconventional monetary policies at the zero lower bound. Finally, part III provides a theoretical and empirical assessment of their macroeconomic consequences. Beyond that, it also includes a short discussion on potential exit strategies from unconventional monetary policies.

Part I After a preliminary discussion of the way monetary policy is implemented in normal times, chapter 2 presents a simple corridor model of the reserve market. Subsequently, this model is used to describe some crisis-driven innovations in monetary policy frameworks. The key result of this chapter is that by replacing large parts of the malfunctioning interbank market with central bank intermediation, the Fed and the ECB succeeded in preventing an ’adverse spiral’ that may have easily unfolded from the heightened uncertainty among money market participants.

As monetary policy in the ’post-Lehman’ era increasingly turned towards lowering the term-premium component of longer-term rates, chapter 3 highlights that the pre-crisis workhorse model of monetary policy analysis – the baseline New Keynesian model (NKM) – is inappropriate to capture such effects. The reason is that the NKM assumes rational expectations, perfectly flexible financial markets, and the existence of the pure expectations theory of the term structure, which altogether offer the rationale for the *Wallace neutrality* of central bank open market operations (Wallace, 1981). Accordingly, the chapter ends with the conclusion that most standard dynamic stochastic general equilibrium models (DSGE) lack the conditions conducive for central bank asset purchases to have a direct effect on either nominal or real economic variables.

Part II The second part starts with a basic classification of unconventional monetary policies. Those are: (i) *forward guidance*, (ii) *quantitative vs. qualitative easing*, and, (iii) *negative policy rates*. In a next step, I construct a preferred-habitat model of the term structure, which provides the theoretical foundation for the *portfolio balance channel* of central bank asset purchases (see chapter 4.2.)

Chapter 5 sheds further light on the transmission channels of unconventional policies. In this context, the predictions of economic theory are cross-checked with the empirical evidence for the US, the UK, and the euro area. Since the focus of this thesis lies on the euro area, in chapter 6, I follow Altavilla et al. (2015) and conduct an event study on the ECB's asset purchase program (APP). In contrast to previous studies, I investigate the set of all official ECB announcements related to the APP over the period from 2014 to 2016. Moreover, I do not confine the analysis to sovereign and corporate bond yields and, thus, provide a more comprehensive perspective on the impact of QE in the euro area. Beyond bond yields, I assess the impact on the European stock markets, on inflation expectations, and on various euro exchange rates. Consistent with the credit risk augmented preferred-habitat theory of chapter 4.2, I find that the APP significantly reduced Italian and Spanish government bond yields, while the effects on German and French yields were much less pronounced. This points to a portfolio balance effect that runs primarily through country-specific risk premia.

Beyond its impact on sovereign bonds, the APP also significantly lowered the yields on euro area corporate bonds (both financial and non-financial). While the announcements led to a significant depreciation of the euro against the US dollar, I do not observe a significant effect on expected inflation and interbank swap rates. Hence, the *signaling channel* and the *inflation reanchoring channel* seem to be less important in the euro area than in the US (see e.g. Bauer and Rudebusch, 2014).

Part III Although the immediate impact on financial markets might be a necessary precondition for the effectiveness of unconventional monetary policy, its ultimate goal is to stabilize inflation and stimulate economic activity. In turn, part III deals with the macroeconomic effects of central bank asset purchases. In this context, firstly, the impact of QE on the banking system is addressed. By taking a closer look at the empirical evidence for the *credit channel* in the UK, the euro area and the US, I reach the conclusion that with the ongoing deterioration in bank capital and the persistent economic slump that followed the failure of Lehman Brothers, the positive impact of additional liquidity increasingly receded. Instead, in the 'post-Lehman' era, any stimulating effect of monetary policy on bank lending acted mainly through the *bank capital channel*.

Given the prevalence of the portfolio balance effect, chapter 8 provides a detailed discussion within a modern DSGE set-up.[1] By drawing on earlier insights from the preferred-habitat theory, this chapter highlights the macroeconomic implications of market segmentation and limits to arbitrage for the effectiveness of central bank asset purchases.

In chapter 8.4, I follow Harrison (2012) and extend the portfolio balance model by including financial intermediaries and the zero lower bound on the short-term policy rate. Thereby, I am able to explicitly account for *two separate* policy instruments at the disposal of the central bank: conventional interest rate policy *and* central bank balance sheet operations. This enables me to simulate the impulse response functions of central bank asset purchases in case of a binding and non-binding zero lower bound. Consequently, the simulation exercise underlines the important result that asset purchases are particularly powerful in stabilizing the macroeconomy at the zero lower bound of the short-term policy rate.

However, the DSGE simulations provide only a qualitative validation for the theoretical predictions about the portfolio balance effect. Therefore, in chapter 9, I conduct a meta study on the existing empirical evidence concerning the macroeconomic effectiveness of unconventional monetary policies in the US, the UK, and the euro area. And while there is a great dispersion among the individual estimates, it seems evident that the macroeconomic impact of the ECB's asset purchase program was substantially smaller than those of the Federal Reserve and the Bank of England.

Finally, chapter 10 outlines some broad principles with respect to exiting unconventional monetary policies. A key finding of this chapter is that a successful exit strategy should likely involve the following steps: first, forward guidance concerning the expected path of future interest rates; second, the application of temporary reserve drainage operations and/or reserve requirements; third, stopping the reinvestment of maturing assets on the central bank's balance sheet and, ultimately, the use of asset sales. Furthermore, I argue that potential central bank losses should not pose a serious constraint on plausible exit scenarios. Chapter 11 concludes.

[1] The model in this chapter is based on Andrés et al. (2004).

Part I.

Monetary Policy and Interbank Markets

2. Monetary Policy Implementation

> "Too often macroeconomic models describe monetary policy as a stock M whose time path is chosen autonomously by a central authority, without clearly describing the operations that implement that policy."
>
> — James Tobin (1982, p. 172)

2.1. Key Terms and Concepts

Theoretical and empirical domains of monetary policy implementation have been subject to various misconceptions due to imprecise or even contradicting definitions of important key terms. To avoid such misunderstandings, this section lays out some conceptual foundations with respect to the monetary policy process. Following Bindseil (2014), firstly this will be done by contrasting *monetary macroeconomics* with *monetary policy implementation*.

Monetary Macroeconomics The main task of central banks' economics departments is to identify the right monetary policy stance to meet their ultimate target, which, under the pre-crisis consensus, meant safeguarding price stability.[1] While the monetary dimension increasingly took the backseat in most central bank operating frameworks, the monetary policy stance is usually expressed in some short-term policy rate. To find the right level of the policy rate, central banks apply macroeconomic models that rely to a great extent on monetary theory.

[1] The experiences of the 2007-09 financial crisis brought the pre-crisis consensus increasingly under scrutiny (Bean et al., 2010). Claims to modify the monetary policy framework included, amongst others: raising the inflation target; switching to a price level target; or assigning monetary policy with an explicit mandate for financial stability. On the other hand, the opponents of such a modification argue that the crisis occurred precisely because policymakers deviated from this framework (Taylor, 2010). Those critics therefore conclude that monetary policy should return to its pre-crisis framework once the economy has sufficiently recovered.

Monetary Policy Implementation Once the adequate stance is identified, the main task of monetary policy implementation is to steer the *operational target* – usually some short-term money market rate – close to the policy rate. Therefore, implementation departments (in the ECB this department is called 'Market Operations') use their monetary policy instruments in order to influence the conditions on the market for central bank reserves.[2] In fact, the salient point for the power of monetary policy is that central banks serve as the monopolistic supplier of reserves in modern fiat money systems. Hence, "the special feature of central banks, then, is simply that they are entities the liabilities of which [reserves] happen to be used to define the unit of account in a wide range of contracts that other people exchange with one another" (Woodford, 2001, p. 347). Evidently, this makes the market for central bank reserves the natural starting point for the implementation of monetary policy.

Separation Principle In normal times, the separation between monetary macroeconomics and monetary implementation, i.e. the separation between the determination of the monetary policy stance and its implementation through liquidity operations, is well defined. In times of financial crisis, however, when the transmission mechanism is impaired, the separation becomes less clear-cut and the way monetary policy is implemented can have direct effects on the monetary policy stance.

This could happen, for instance, when during a crisis funding constraints become binding, which may cause a breakdown of the usual arbitrage relationship between short- and long-term interest rates. Since this implies that the short-term policy rate loses its property as a sufficient operational target for monetary policy, central banks often respond by adopting unconventional measures to directly impact upon different elements of the transmission mechanism. Of course, this is exactly what happened during the recent financial crisis, when central banks around the globe tried to directly control longer-term rates, widened their collateral frameworks, or enlarged the set of counterparties eligible for central bank refinancing operations. As some of these measures fall in the realm of monetary policy implementation, it seems justified to devote some thoughts to this topic.

[2]Loosely defined, reserves are funds that commercial banks hold in their deposits ('current accounts') with the central bank. Most central banks oblige commercial banks to hold a certain amount of their liabilities as *required reserves*, but even if no reserve requirements are imposed, commercial banks generally hold some positive reserve levels due to market frictions or transaction costs.

2.1.1. Monetary Policy Targets

The collapse of the Bretton-Woods-System of fixed exchange rates in 1973 allowed the policymakers of advanced economies to shift their focus from external to internal targets of monetary policy. And while the 1970s were characterized by high and volatile inflation episodes, by the end of the decade the consensus had been achieved that monetary policy should be geared towards price stability (Goodfriend, 2007). However, this does not mean that monetary policymakers focus solely on price stability. Additional goals may include a high level of output and employment, financial stability, or a stable exchange rate.

Eurosystem The European System of Central Banks (ESCB) consists of the European Central Bank (ECB) and the national central banks (NCBs) of the EU Member States. As the national central banks of EU Member States who do not use the euro as legal tender retain their autonomy in the conduct of monetary policy, the term NCBs throughout this dissertation will refer to central banks whose currency is the euro. The ECB and those NCBs whose currency is the euro constitute the Eurosystem.[3]

The relevant legal basis for the monetary policy activities of the European System of Central Banks constitutes the 'Treaty on the Functioning of the European Union' as well as the 'Statute of the ESCB'. According to Article 127(1) of the Treaty, the primary objective of the ECB is to maintain price stability, which the Governing Council specified as "maintain inflation rates below, but close to, 2% over the medium term".[4] Without prejudice to the first principle of price stability, the Eurosystem shall also support the general economic policies in the Union. In particular, it should strive for a high level of employment and a balanced development of economic activities in the euro area.

Federal Reserve Compared to the Eurosystem, the US government has a bigger and more direct impact on the Fed's monetary policy targets. In fact, the 'Humphrey-Hawkins Full Employment Act' of 1978 not only mandated the Fed to promote full employment and low inflation, but also specified the numerical targets for this so-called dual mandate to be 4% for full employment and 3% CPI inflation for price stability (Judd and Rudebusch, 1999). As a consequence, the members of the Federal Open Market Committee (FOMC), i.e. the decision making body of the Federal Reserve, are left to decide upon the means and measures they think are best to pursue those prespecified

[3]In the following, the terms ECB and Eurosystem are used interchangeably.
[4]The ECB's definition of price stability as of March 2014 is available on https://www.ecb.europa.eu/mopo/strategy/pricestab/html/index.en.html.

goals. Compared to the euro area, where there is no directly responsible national parliament above the ECB and the monetary policy targets being fixed in an essentially inviolable Treaty, the Fed is relatively less independent than the Eurosystem – at least from an institutional perspective. However, this comparative advantage in central bank independence should not conceal the various shortcomings that are linked to the ECB's role as a supranational central bank of a non-optimal currency area.

Additional Targets In fact, the experience gained during the financial crisis raised some new issues concerning the Eurosystem's mandate and governance structure. The crisis proved the existing institutional organization of the euro area, where supervision of financial institutions was carried out primarily on the national level, insufficient to appropriately address the matters of systemic risk and financial stability. As a response, the European Parliament, on 12 September 2013, adopted the European Commission's proposal to create the Single Supervisory Mechanism (SSM), which will confer specific regulatory and supervisory tasks to the ECB. After the implementation of the SSM, the ECB will have essentially two arms - a supervisory and a monetary policy arm. The latter will still be confined to safeguard price stability. Although the ECB's new supervisory task and its coordination with monetary policy is part of an ongoing debate in academia (cf. Beck and Gros (2012)), this thesis will limit the discussion to the classic monetary policy perspective. In this respect, Article 127(2) of the Treaty in conjunction with Article 3(3.1) of the Statute of the ESCB lays out the basic tasks the monetary policy branch of the Eurosystem should pursue. Those are (i) to define and implement the monetary policy of the Union; (ii) to conduct foreign-exchange operations; (iii) to hold and manage the official reserves of the Member States; (iv) to promote the smooth operation of the payment system.

2.1.1.1. Intermediate Targets

Although the importance of *intermediate targets* declined constantly since the end of the 1980s, they have a prominent, though not very successful, track record in the history of monetary policy. The Bundesbank, for instance, adopted a growth rate for base money as an intermediate target from 1975 until 1988.[5] Arguments in favor of intermediate targets usually presume that they can be controlled with a certain degree of precision and that they show a stable relation to the final target. Since both presumptions were

[5] Due to the high and volatile currency ratio contained in the monetary base, the Bundesbank changed its intermediate target to M3 in 1987.

constantly refuted by practical experience, intermediate targets were downgraded to be mere *indicator variables*. An indicator variable is supposed to contain valuable information with respect to the final target but does not necessarily imply that the operational target has to react in a systematic fashion.

A crucial determinant of successful monetary policy making is a good model of the transmission mechanism. That is, policymakers have to know how the short-term operational target, indicator variables, intermediate targets, exogenous shocks, and ultimate targets are dynamically linked. Fig. 2.1 shows the different levels of monetary policy which are part of this process. The central task of monetary macroeconomics is then to

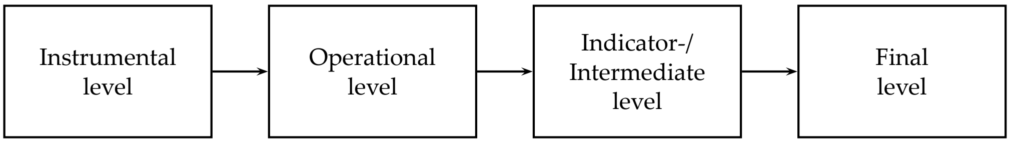

Figure 2.1.: Monetary policy levels

uncover the causal relations between these different levels and to extract the optimal response of the policy rate. This might become particularly difficult during crisis times, when established correlations break down.

2.1.2. Monetary Policy Strategy

How the operational target is employed to optimally achieve the ultimate target is a matter of *monetary policy strategy*. It defines how the central bank adjusts the operational target in response to shocks and how it communicates with the public. Monetary policy strategies can be quite simple or rather complex. A rather simple strategy is an instrument rule like the Taylor-Rule, which tells the central bank how to set the short-term nominal interest rate for a given state of the economy (see equation ⟨8.75⟩ in section 3.1).

An example of a more complex monetary policy strategy is the ECB's so-called *two-pillar approach*, which consists of the economic analysis and the monetary analysis. The former aims at assessing the short to medium-term determinants of price developments, focusing mainly on real activity and cost push factors over that horizon. Amongst the variables of interest are developments in overall output, aggregate demand and fiscal policy; a broad range of price indicators; capital and labor market conditions; developments in the exchange rate and the balance of payments as well as financial markets and the balance sheet positions of euro area sectors (ECB, 2011).

On the other hand, the monetary analysis focuses on a medium to longer-term horizon. It aims at exploiting the robust relationship between monetary growth and inflation over the medium to long run. Therefore, the ECB tracks a reference value for the growth rate of the broad monetary aggregate M3, although it does not react mechanically to deviations from M3 from its reference value. Hence, the ECB notes that "the lags with which protracted deviations of monetary dynamics from historical norms lead to risks to price stability can be long and varying" (ECB, 2011, p. 80). Therefore, the ECB de facto downplayed the role of money in its monetary strategy along a number of dimensions. As a consequence, market participants also ceased to attach much weight on the ECB's monetary pillar (Geraats et al., 2008) – at least prior to the financial crisis. More recently, however, it has been stressed that the monetary pillar should be revived in order to incorporate systematic information about the state of financial markets into the monetary policy process (Galí, 2010; Brunnermeier and Sannikov, 2014b).

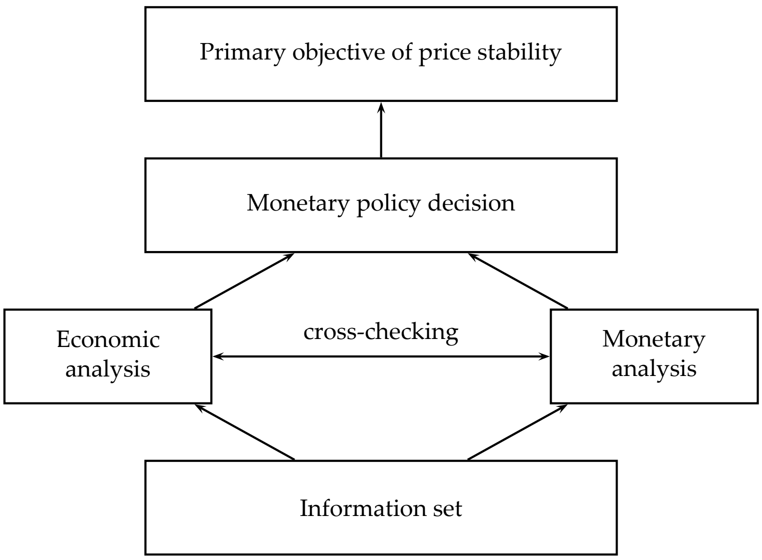

Figure 2.2.: Monetary policy strategy of the ECB

2.1.3. Monetary Policy Instruments

To implement the operational target, central banks are equipped with *monetary policy instruments*. These days, central banks predominantly employ three kinds of instruments: *reserve requirements*, *open market operations*, and *standing facilities*. The optimal application of these monetary policy instruments, i.e. managing the terms and conditions on the market for reserves in such a way that the operational target is made effective, is also called *central bank liquidity management*.

Reserve Requirements Central banks use *required reserves* and – in case of non-required reserve regimes – may provide incentives for banks to hold *voluntary reserves*. One function of commercial banks holding reserve accounts with the central bank is to create demand for central bank liabilities in order to facilitate central bank forecasts of base money demand. This is sometimes called the *connectivity function* of reserves (e.g. Goergens et al., 2014, p. 112). Moreover, if a reserve regime with averaging is applied, this can help to stabilize the volatility of the interbank rate (sometimes called the *stabilization*, or *buffer function* of reserves).

Open Market Operations In normal times, *open market operations* serve as the primary tool to supply/absorb reserves to/from the banking system. They are conducted at the central bank's initiative and are used to steer the interbank rate towards its operational target. Generally, two types of open market operations can be distinguished: firstly, outright purchases or sales of assets (usually public debt securities); secondly, temporary lending operations (usually in the form of repurchase agreements), which are conducted through different types of tender procedures (variable or fixed-rate tender procedures).[6]

Standing Facilities Finally, central banks employ *standing facilities*. These are in fact the oldest of all monetary policy instruments. Contrary to open market operations, standing facilities are permanently available during business hours and can be tapped at discretion of eligible counterparties. This is especially relevant at the end of business days when the interbank market has already closed. In practice, there exist three kinds of standing facilities:

i. *Discount Facility*: The discount facility was the predominant monetary policy instrument until the middle of the twentieth century. In classical dis-

[6] For details, see e.g. Bindseil (2014, Chapter 7).

counting, eligible counterparties could at any time place some kind of short-term commercial paper (or 'real bill') in a special account with the central bank. The central bank then set the discount rate in this operation by discounting the bill's face value based on risk characteristics and monetary policy objectives. At maturity, the bill had to be redeemed by the final borrower. Today, advanced central banks do not use this type of discount anymore. Nevertheless, some central banks, like the Federal reserve, use the name discount facility for their borrowing facility.

ii. *Borrowing Facility*: contrary to classical discount borrowing, recourse to a modern borrowing facility (also called *Lombard* or *advance facility*) means taking out a loan from the central bank at given rates and for standardized maturities. In principle, eligible counterparties can borrow unlimited amounts during business hours given that they provide sufficient collateral. The borrowing facility is thus economically similar to the discount facility, in the sense that both are liquidity providing facilities, although the technical details of both facilities differ rather substantially. Most importantly, access to a borrowing facility is granted only at a surcharge above the prevailing market rate (penalty rate system). Furthermore, modern borrowing facilities are cost efficient and allow for broader collateral frameworks, since the maturity of the credit operation is no longer tied to the residual maturity of the discounted bill. As a consequence, modern central banks predominantly provide collateralized credit facilities and do not employ classical discounting anymore.

iii. *Deposit Facility*: this is the only liquidity absorbing standing facility available to monetary policy implementation. Eligible counterparties can place funds in special accounts with the central bank. Whereas other central bank accounts normally pay no interest, funds placed in the deposit facility get remunerated at the deposit rate. Banks with excess reserves thus face the alternatives of depositing with the central bank or lending in the interbank market.

Misconceptions Regarding the Fed's Discount Window Unfortunately, the Fed still calls its borrowing facility 'discount window'. This misnomer can be thought of as a historical relict which is incorrect for certain reasons: firstly, already since the late 1960s, virtually all funds that flowed through the Fed's discount window took the form of collateralized credit (Board of Governors of the Federal Reserve System, 1974, p. 71). Secondly, the Fed significantly revised its discount policy in 2003 and set the discount facility's interest rate above the federal funds target rate (Board of Governors of the Federal Reserve System, 2005, p. 47). Therefore, the Fed's discount window is finally equivalent to a standard borrowing facility at penalty rates. Nevertheless, at least so far, the Fed has not changed its name accordingly.[7]

Misconceptions Regarding the Poole Model With respect to the optimal choice of the monetary policy instrument, the influential article of Poole (1970) caused widespread confusion and lead to an ambiguous understanding of the term. Poole (1970) showed in an IS-LM framework that monetary policy should adopt different 'instruments' according to the nature of the stochastic shock that hits the economy. In his model, when the economy is subject to a money demand shock, the optimal monetary policy response is to fix the nominal interest rate and let the money supply adjust endogenously.

If the economy is hit by a real shock, instead, the money supply should be fixed in a way that the nominal rate can stabilize output accordingly. Very importantly, however, the 'M' in the IS-LM model stands for the money stock, *not* for base money! This is problematic insofar as Poole referred to the alternative between interest rate and money stock targeting as the 'optimal choice of monetary policy instruments'. The money stock, however, includes commercial bank liabilities which ultimately result from the credit decisions of banks and the non-bank public. Thus, if the central bank wants to influence broader monetary aggregates, it can do so only indirectly by affecting the opportunity costs of banks' credit supply.

Since, in reality, the central bank can exert direct control only over the base money supply, the Poole model must implicitly assume a stable money multiplier. This, however, does not hold in practice. Another factor is that modern central banks typically supply base money endogenously in order to facilitate a smooth functioning of interbank markets. Overall, this implies that Poole's alleged instrument choice problem is not really a choice. The problem is rather that it blurs the distinction between the instrumental, operational, and intermediate level of monetary policy implementation (see Fig. 2.1) and this mistake is based on the "apparent lack of distinction between base money

[7]To be precise, the Fed's discount window comprises four types of credit: primary credit, secondary credit, seasonal credit, and emergency credit. Eligibility criteria and interest rates differ for each credit type. But since most depository institutions qualify for primary credit - secondary credit is available at a premium to the primary rate for those institutions that do not qualify for primary credit - and because primary credit is the main discount window program, the terms primary rate and discount rate are often used interchangeably.

and the money supply, deriving from the combined behaviour of the central bank and commercial banks" (Papadia, 2005, p. 54).

2.1.3.1. Interest Rates as Operational Targets

According to Bindseil (2011), for a variable to qualify as operational target it has to fulfill at least the following four conditions: firstly, it has to be *tractable*, i.e. the central bank must have sufficient control over it; secondly, it has to be *relevant* in terms of effectively affecting the ultimate monetary policy target; thirdly, it has to effectively *signal* the stance of monetary policy to the public; and fourthly, it has to provide *guidance* to monetary policy implementation on how to make the operational target effective in the market.

Over time, the overnight interbank rate turned out to be the most adequate to meet these criteria, such that prior to the global financial crisis, basically all western central banks targeted some kind of short-term nominal interest rate. Despite this convergence, however, the implementation of interest targeting slightly differed among central banks.[8]

Overnight interbank rates were targeted directly, among others, by the Fed, the Bank of Canada (BoC), the Bank of England (BoE), and the Bank of Japan (BoJ).[9] In those countries, the *policy rate* in effect equaled the *target rate* implying that tender rates on central banks' refinancing operations played no independent signaling role.[10] At least until the crisis, the ECB followed a slightly different approach. It explicitly targeted the minimum bid rate in its variable rate tender operations, instead of an interbank overnight rate. Implicitly, however, the ECB also targeted an overnight interbank rate, namely the euro overnight index average (EONIA) rate (Amstad and Martin, 2011).

A notable exception with respect to the maturity of the operational target is given by the Swiss National Bank (SNB). Among the central banks considered, the SNB is the only one using a range for a longer-term rate (the three-month Libor) as its operational target. Other differences amount to targeting collateralized (BoC, BoE, ECB) or uncollateralized (BoJ, Fed, SNB) refinancing rates. These institutional differences in monetary policy frameworks - although important from a technical perspective - played no sig-

[8]See Borio (1997b) for a survey on implementation practices in the late 1990s or Markets Committee (2009) and Amstad and Martin (2011) for more recent studies.

[9]On April 4, 2013 the BoJ ceased to target the overnight call rate and adopted a monetary base target instead.

[10]Generally, the policy rate is the interest rate which best captures the central bank's policy intentions.

nificant role for the effectiveness of monetary policy implementation, at least prior to the financial crisis. In fact, all major central banks coped rather well with the difficult task of minimizing the spread between the market and the policy target rate, especially when they implemented it by means of a corridor system (see section 2.2 and Figure 2.5, respectively).

Historical Excursus: The Debate over 'Rates vs. Quantities'

Probably the first advocate of interest rates as operational targets was Thornton, who wrote already at the beginning of the 19th century: "[The Bank of England] might, undoubtedly, at all seasons, sufficiently limit its paper by means of the price at which it lends, if the legislature did not interpose an obstacle to the constant adoption of this principle of restriction" (Thornton, 1807, p. 242).

In its first years of existence, however, the Bank of England (BoE) neither set its discount rate to prevent an over-issue of notes, nor did it employ price incentives to control for macroeconomic stability. It rather granted credit to the royal court, as the bank charter and the right to issue notes was coupled with the expectation that the Bank would help to finance the court's substantial debt at preferential rates (Homer, 1977).

That the Bank did not use its discount rate as an active monetary policy tool can also be inferred from the fact that the rate was kept at five percent for almost the whole 18th century, whereas the rates on state bonds fell considerably. The resulting, very persistent inverse term structure contributed to private sector borrowing and stimulated investment. Besides the positive growth effect – and although probably unintentionally – this policy may have also stabilized the money market, as the Bank simultaneously limited its note issue but stood ready to act as a lender of last resort in times of crisis.

In contrast to modern fiat monetary systems, however, the BoE's early experiences with monetary policy implementation were characterized by the binding restrictions of the gold standard. The dominant concern of monetary policy during the gold standard was the availability of sufficient gold reserves to maintain the convertibility between national currencies and gold at the legal parity. With regard to monetary policy implementation, however, the BoE learned to distinguish between *internal* and *external* drains of gold (Spahn, 2001). The former were seen as reflecting what modern central banks would consider autonomous liquidity factors, such that gold flows were accepted without triggering an automatic reaction in the Bank rate. In contrast, persistent external drains due to trade or interest rate differentials were seen as a threat to convertibility and were thus answered by tightening the monetary policy stance, i.e. by an increase in the Bank rate.

As a consequence, money market liquidity was depending on the BoE's discount window and hence its 'Bank rate' policy already before the nineteenth century (King, 1945). Hence, the BoE followed Thornton's dictum and deliberately chose a short-term rate as operational target at quite an early stage. Finally, in the high times of the gold standard (1870-1914), the BoE succeeded in making the Bank rate effective by implementing a structural liquidity deficit vis-à-vis the central bank and systematically exploiting the interplay between open market operations and the discount facility. In doing so, reserves were supplied endogenously and quantitative restrictions – much in line with contemporary practice in monetary policy implementation – were of minor relevance. Referring to the slope of the reserve supply function, Moore (1988) called this the 'horizontalist' approach to monetary policy implementation.

Somewhat surprisingly, the theoretical insights of Thornton as well as the practical experience of the BoE seemed to be discarded by the Federal Reserve, which began to conduct monetary policy in 1914 relying primarily on quantitative targets (Meulendyke, 1998; Meltzer, 2003). Moreover, with the rise of the monetarist paradigm in the 1960, the role of quantity targets for monetary policy was further emphasized (Cagan, 1956; Friedman and Schwartz, 1963). As a result, the consensus to choose 'rates over quantities' emerged rather slowly over the course of the twentieth century.

2.1.4. Monetary Policy Transmission

The *monetary policy stance* is necessarily a relative concept and crucially dependent on economic circumstances. Whether monetary policy is perceived as loose or tight cannot be answered irrespective of some neutral benchmark or *natural rate of interest*. Contemporary standard Neo-Wicksellian macroeconomic models in the spirit of Woodford (2003) define a neutral stance of monetary policy as a situation where the central bank keeps the short-term nominal interest rate - the *bank rate* in Wicksellian parlance - in line with the natural rate. The natural or real rate of interest is determined by fundamental forces and is thus derived in the the real sphere of the economy. Only if this condition is warranted do prices remain in stable equilibrium. As Wicksell noted already in 1898:

> "There is a certain rate of interest on loans which is neutral in respect to commodity prices, and tends neither to raise nor to lower them. This is necessarily the same as the rate of interest which would be determined by supply

and demand if no use were made of money and all lending were effected in the form of real capital goods. It comes to much the same thing to describe it as the current value of the natural rate of interest" (Wicksell, 1936, p. 102).

The basic idea of a natural rate of interest with stable prices is illustrated in Figure 2.3. It shows a two-good-two-period economy with relative prices. Consider the real good

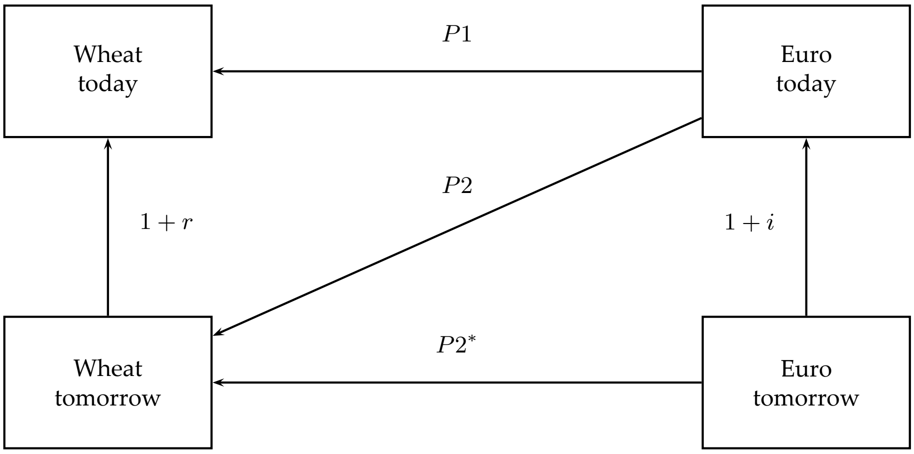

Figure 2.3.: Wicksellian arbitrage diagram ⋄ *Source:* Richter (1990, p. 55)

as a bundle of wheat and the nominal good as currency (Euro). Today, the real good (wheat) is sold for a price $P1$ in money units and costs $P2$ on the future market. Tomorrow, the real good costs $P2^*$ in money units. If we abstain from consuming wheat today but instead sow the seeds in order to consume tomorrow, we will be able to harvest $(1 + r)$ units of wheat tomorrow. In this simple example, one can think of the real rate as determined by nature only. In reality, however, this rate is equal to the marginal productivity of capital, thus depending on the economy's production function determined by numerous factors subject to shocks. Abstracting from shocks, intertemporal arbitrage ensures that in equilibrium, the following condition must hold:

$$1 + r = P1/P2 = P1(1 + i)/P2^* \quad \langle 2.1\rangle$$

If gross inflation is defined as $P2^*/P1 = 1 + \pi$, equation 2.1 can be transformed into the well-known Fisher equation

$$1 + r = (1 + i)/(1 + \pi) \tag{2.2}$$

This illustrates nicely the important implications for monetary policy presented above. Whenever the central bank sets its operational target equal to natural rate of interest ($i = r$), it follows from equation ⟨2.2⟩ that net inflation must be zero.

If, however, $i < r$ and inflation expectations were constant, then arbitrageurs would borrow today at the nominal rate to invest in real goods and sell them tomorrow. For a given production level, this will lead to rising goods prices today until the arbitrage opportunity vanishes and equilibrium is restored. Consequently, monetary policy is able to influence the evolution of prices - at least temporarily - whenever it drives a wedge between the *nominal* and the *natural* rate of interest (the Wicksellian interest rate gap). Of course, this arbitrage logic is a very simplifying example of the basic intuition behind the interest rate policy actually pursued by modern central banks. In reality, finding the right monetary policy stance is a complicated and resource-intensive analytical task mainly performed in central banks' economics departments.

2.2. Simple Corridor Model of the Reserve Market

In recent years, many central banks moved away from implementing monetary policy mainly through open-market operations. Instead, they designed their monetary policy frameworks to work more automatically by making greater use of standing facilities. This kind of system is called a *corridor* or *channel system* of the reserve market. Versions of corridor systems are now, amongst others, implemented by the European Central Bank, the Federal Reserve, the Bank of England, the Swiss National Bank, the Bank of Canada, the Reserve Bank of Australia and the Reserve Bank of New Zealand (Bernhardsen and Kloster, 2010). To illustrate its basic mechanisms, the following section presents a simple corridor model of the reserve market.[11]

Preliminaries There are n banks in the model, each holding a reserve account with the central bank. Banks use their reserve accounts to settle transactions arising from the

[11] The model of this section builds on Sheedy (2014) with many insights coming from Bindseil (2000, 2004); Heller and Lengwiler (2003); Whitesell (2006); Berentsen and Monnet (2008).

interbank payment system. This could arise, for example, when a customer of bank A makes a deposit transfer to the customer of bank B. Therefore, banks borrow reserves from one another on the interbank market. This interbank borrowing is usually very short-term and uncollateralized, which makes it potentially risky from a lender's perspective. Importantly, however, due to the stochastic nature of their customers transactions, banks do not know with certainty how much reserves they will need at the point they participate in the interbank market.

As an alternative to the interbank market, banks can borrow reserves on the repo market. In a repo agreement, the seller of a bond (e.g. a government bond) agrees to repurchase that same bond at a slightly higher price in the future, where the difference between today's price and the predetermined higher future repurchase price is the so-called repo rate (reflecting the borrowing rate in this transaction). Thus, a repo agreement effectively equals a collateralized loan, making it risk-free in the case of good collateral.

For simplicity, we assume that all repo agreements are risk-free and that the central bank is the only lender on the repo market. Moreover, we assume that banks typically do not default on their interbank obligations, so these loans are also perceived to be risk-free. In other words, the repo rate equals the interbank rate, which seems to be a reasonable presumption for normal times. Furthermore, we abstract from reserve requirements.

2.2.1. Symmetric Corridor System

In the absence of period-average reserve requirements, a corridor system can be represented by a one-day model (Whitesell, 2006). Thus, with RH_j as the initial reserve holdings of bank j; I_j as net interbank borrowing (negative for lending); RP_j as net repo lending; T_j as uncertain net transfers to other banks; and R_j as the reserve balance of bank j's central bank account, the flow budget constraint is given as

$$R_j = RH_j + I_j + RP_j - T_j. \tag{2.3}$$

At the end of the day, the central bank pays the deposit rate i_d on positive balances in banks' reserve account, while it charges a borrowing rate i_b on negative balances. In practice, banks can borrow unlimited amounts through the borrowing facility given that they have sufficient collateral. Here, we assume that banks have enough collateral, so no quantity constraint occurs.[12] With i as the uniform interest rate on repo and interbank loans, the central bank sets the rate on the standing facilities such that $i_d < i < i_b$. If $R_j \geq 0$, the reserve balance of bank j at the beginning of the next period, i.e. after interbank, repo and the deposit facility are settled, is given by

$$RH'_j = R_j - (1+i)(I_j + RP_j) + i_d R_j. \tag{2.4}$$

On the other hand, if $R_j < 0$, banks have to turn to the borrowing facility such that the reserve position at the beginning of the next period equals

$$RH'_j = R_j - (1+i)(I_j + RP_j) + i_b R_j. \tag{2.5}$$

Ultimately, whether banks have a positive or negative reserve balance at the end of the period depends on the realization of T_j. Thus, substituting equation ⟨2.3⟩ into ⟨2.4⟩ and ⟨2.5⟩ yields

$$RH'_j = RH_j - i(I_j + RP_j) - T_j + i_d(RH_j + I_j + RP_j - T_j) \tag{2.6}$$

and

$$RH'_j = RH_j - i(I_j + RP_j) - T_j + i_b(RH_j + I_j + RP_j - T_j) \tag{2.7}$$

respectively. Importantly, we assume that the realization of T_j happens after the interbank and repo market has closed. Consequently, banks aim to maximize expected next period reserve balance, $E[RH'_j]$, by choosing I_j and RP_j subject to the density function $f(T_j)$. The objective function of bank j thus reads

$$\begin{aligned} E[RH'_j] = RH'_j - i(I_j + RP_j) + i_d \int_{T_j \to -\infty}^{RH_j + I_j + RP_j} (RH_j + I_j + RP_j - T_j) f(T_j) \mathrm{d}T_j \\ + i_b \int_{T_j = RH_j + I_j + RP_j}^{T_j \to \infty} (RH_j + I_j + RP_j - T_j) f(T_j) \mathrm{d}T_j. \end{aligned} \tag{2.8}$$

[12] This seems justified, because central banks typically either widen their collateral frameworks or lower their eligibility criteria when collateral becomes scarce or its quality deteriorates.

Since the two first-order conditions,

$$\frac{\partial E[RH'_j]}{\partial I_j} = 0 \quad \text{and} \quad \frac{\partial E[RH'_j]}{\partial RP_j} = 0, \qquad \langle 2.9 \rangle$$

lead to the same equation, we only have to consider one. As shown in the Appendix B.1, calculating the first-order condition yields

$$(i_b - i)(1 - F(RH_j + I_j + RP_j)) = (i - i_d)F(RH_j + I_j + RP_j), \qquad \langle 2.10 \rangle$$

where $F(.)$ denotes the distribution function of the interbank reserve shock $f(.)$. This equation states that bank j chooses the optimal amount of interbank and repo borrowing (resp. lending) in such a way that it minimizes two types of costs: the opportunity costs of having to borrow from the central bank rather than from the market, given by $(i_b - i)$, and the opportunity costs of holding a positive end-of-day balance in the deposit facility, relative to lending those funds in the market, given by $(i - i_d)$. Similarly, equation ⟨2.10⟩ can be written as

$$F(RH_j + I_j + RP_j) = \frac{i_b - i}{i_b - i_d} \qquad \langle 2.11 \rangle$$

Since we know that $0 \leq F(RH_j + I_j + RP_j) \leq 1$, the optimality condition implies that the repo rate i is always bounded by the corridor of i_b and i_d, because money market participants would never agree to trade at an interest rate that lies outside this corridor.[13] Furthermore, since the initial reserve holdings RH_j are predetermined and the reserve supply through the repo market is determined by the central bank, the optimality condition also implies that banks with a high value of RH_j are likely to become net lenders on the interbank market and/or the repo market for reserves (i.e. $I_j + RP_j < 0$)

Market Clearing Summing over all n banks gives the aggregate beginning-of-day reserve balances, $RH = \sum_{j=1}^{n} RH_j$, and the aggregate end-of-day balances, $R = \sum_{j=1}^{n} R_j$. Since transfers between banks and interbank payments cancel each other out in the aggregate, we get $\sum_{j=1}^{n} T_j = 0$, and equivalently, $\sum_{j=1}^{n} I_j = 0$. Further, all repo market transactions net out to the central bank's open-market operations, i.e., $\sum_{j=1}^{n} RP_j = RP$,

[13] In practice, however, money market rates occasionally lie outside this corridor. This can often be explained by institutional factors relating to a particular operating framework. In the US, for instance, some big players on the federal funds market (e.g. Fannie Mae and Freddy Mac) have no access to the Fed's deposit facility, which can explain why US short-term rates occasionally dropped below the deposit rate when the reserve supply was massively increased during the financial crisis.

where RP are the central bank's repurchase agreements. From

$$R_j = RH_j + I_j + RP_j - T_j \quad \langle 2.12 \rangle$$

it thus follows that

$$R = RH + RP \quad \langle 2.13 \rangle$$

such that RP is the net injection of reserves by the central bank. And since $R_j = RH_j + I_j + RP_j - T_j$ is the same for all banks, it holds that

$$RH_j + I_j + RP_j - T_j = \frac{R}{n}. \quad \langle 2.14 \rangle$$

As a consequence, the equilibrium interbank interest rate as well as the repo rate i are determined by the equation

$$F\left(\frac{R}{n}\right) = \frac{i_b - i}{i_b - i_d} \quad \langle 2.15 \rangle$$

where the central bank directly sets both i_b and i_d as well as the net reserve supply RP. Thereby, the central bank indirectly determines not only the total reserves at the end of the period, i.e. $R = RH + RP$, but also the equilibrium interbank and repo rate i^*.

It should also be noticed that equation ⟨2.15⟩ implies a negative relation between the aggregate end-of-day reserve balances R and the repo or interbank rate i. Thus, the reserve demand schedule in Figure 2.4 displays a negative slope. Given that net reserves are supplied at the central bank's discretion, the graph depicts a vertical, interest-inelastic reserve supply schedule R^S. A net increase (decrease) in the reserve supply will lead to a lower (higher) equilibrium interbank rate i^*.

If, however, net interbank transfers T_j have a symmetric probability distribution – which we can reasonably assume for large numbers of banks due to the central limit theorem – then targeting a zero reserve balance ($R = 0$) implies that the equilibrium rate will be exactly in the midpoint between the central bank's lending and deposit rate.

Advantages of Symmetric Corridor Systems In fact, a symmetric corridor system has considerable advantages over traditional reserve systems. In traditional, non-symmetric reserve systems, changing interest rates require a carefully calibrated open-market ope-

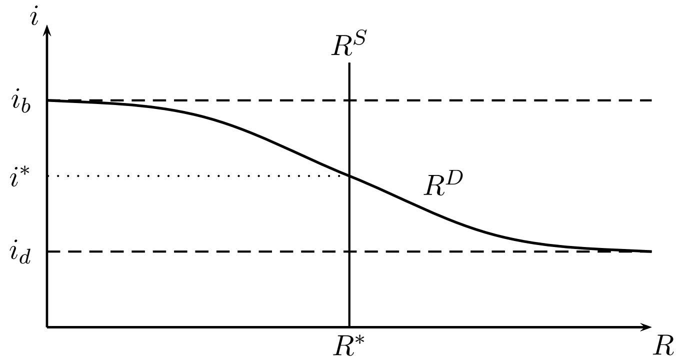

Figure 2.4.: Symmetric corridor system

ration for which the policymaker has to have good knowledge about the money demand function. This is unnecessary if the central bank operates a symmetric corridor system. Changing the target interest rate only requires a parallel shift of the standing facility rates.

To see this, imagine that the policymaker wants to increase its policy rate target by x basis points, i.e. $i' = i + x$. If the two standing facility rates are increased by the same amount, the optimality condition ⟨2.15⟩ implies

$$\frac{i'_b - i'}{i'_b - i'_d} = \frac{(i_b + x) - (i + x)}{(i_b + x) - (i_d + x)} = \frac{i_b - i}{i_b - i_d} = F\left(\frac{R}{n}\right) \qquad \langle 2.16 \rangle$$

showing that no open-market operation is required to increase the target rate ($R' = R$). The reason is that the reserve demand depends on the interbank rate *relative* to the standing facilities in a corridor system. Another advantage over traditional reserve systems can also be inferred from the lower volatility of money market rates. This becomes most evident by comparing the volatilities of the respective money market rates in the US (traditional system) and Australia (corridor system) in upper two panels of Figure 2.5. Notice that during this period the Fed set the rate on its discount window *below* the fed funds target rate.

The Fed changed this procedure in January 2003 when it introduced its discount window for primary credit which traded 100 basis *above* the target rate. It seems that this change in the Fed's implementation framework contributed to the successful steering of money market rates until the onset of the financial crisis (see the lower left panel in Figure 2.5).

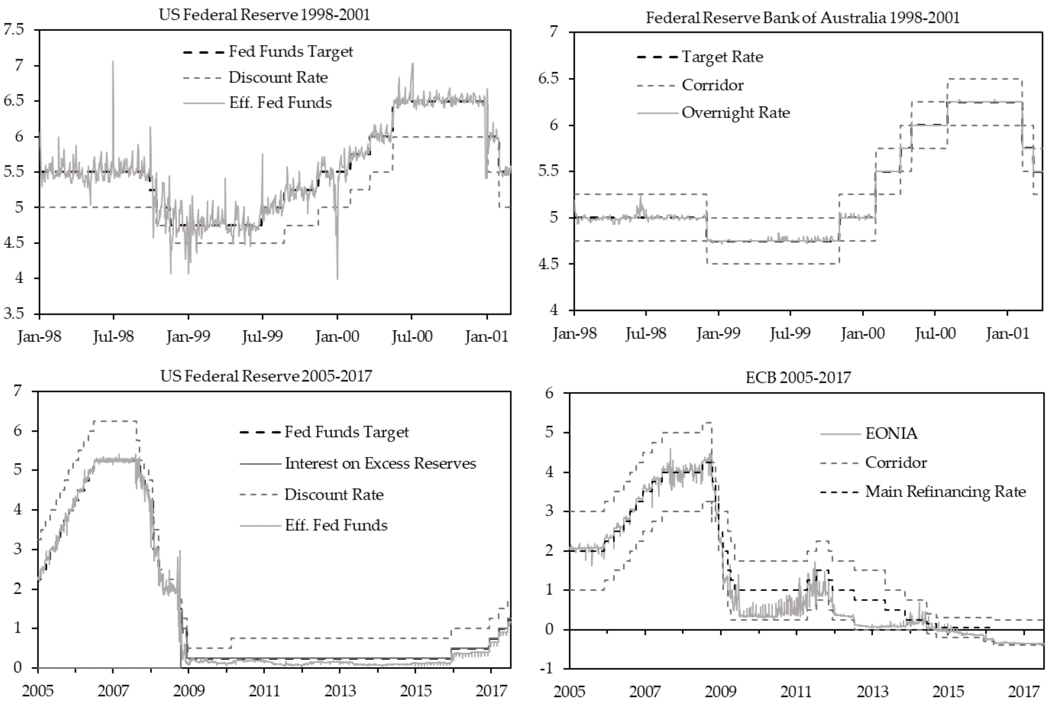

Figure 2.5.: Implementation systems ⋄ *Source:* Federal Reserve Bank of the United States, Federal Reserve Bank of Australia, ECB, Datastream

Finally, as part of the Emergency Economic Stabilization Act of 2008, the US Congress granted the Fed the authority to pay interest on excess reserves (IOER) that depository institutions ('banks') held with the Federal Reserve System. Interestingly, however, non-depository institutions (such as government-sponsored enterprises (GSEs)), which traditionally represent important players on the US money market, were *authorized* to hold overnight balances at the Fed, but were *not legally eligible* to receive interest on those balances. Hence, this institutional discrimination across market participants created a segmented reserve market, which, in conjunction with unexploited arbitrage opportunities, has driven the effective federal funds rate consistently below the IOER rate (sometimes as much as 20 basis points).[14] This 'slippage' in the effective federal funds rate contrasts with the experience concerning the Eurosystem. As the latter grants access to its deposit facility to a very wide range of counterparties, its IOER rate puts an effective lower bound on short-term funding rates (compare the lower panels in Figure 2.5).

Optimal Corridor Width When choosing the optimal width of a corridor system, policymakers face an inherent trade-off between stabilizing money market rates and maintaining an active interbank market. On the one hand, a relatively wide corridor provides a strong incentive for banks to trade on the interbank market rather than relying on central bank standing facilities, which is socially desirable for various reasons. For instance, in the case of asymmetric information and excessive risk-taking on the part of borrowers, private markets could induce market discipline and simultaneously, by minimizing the use of standing facilities, shield the central bank from taking on too much credit risk (Allen, 2002; Repullo, 2005; Hoerova and Monnet, 2016). On the other, if there are aggregate liquidity shocks, a wide corridor would result in relatively strong fluctuations of short-term funding rates. Thus, if the central bank wants to control market rates, this would principally call for setting the corridor width to zero. Section 2.2.4 provides a more detailed discussion of such an operating framework.

Reserve Demand Shocks and Fine-Tuning Operations Importantly, a corridor system does not mean that the central bank can abstain from any reserve intervention. If, for example, the uncertainty about interbank payments changes, the cumulative distribution function $F\left(\frac{R}{n}\right)$ changes as well, which will lead to a shift in the reserve demand

[14] A straightforward interpretation for this spread is that banks face transaction costs when they borrow funds from the GSEs. Another reason is that banks face balance sheet costs when they borrow in the federal funds market and invest the proceeds in their reserve accounts with the Fed (e.g. higher capital costs or higher deposit insurance costs associated with higher reserve holdings). For a detailed discussion on these issues, see chapter 10 as well as Bowman et al., 2010; Bech and Klee, 2011 and Martin et al., 2013.

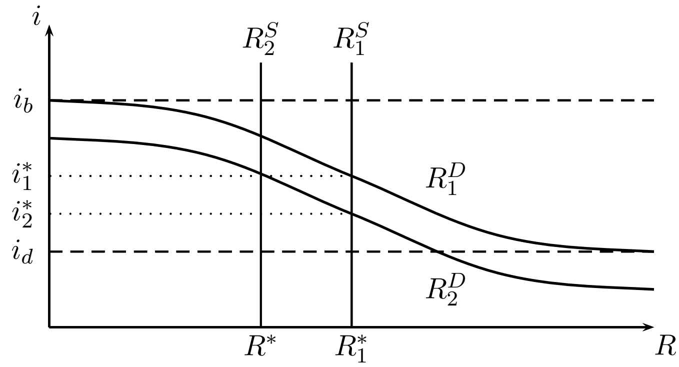

Figure 2.6.: Reserve demand shock with fine-tuning

schedule. One possibility is that bank customers inject reserves by substituting cash for bank deposits. As this will increase the probability of having excess reserves at the end of the period, banks' reserve demand shifts downwards, causing a fall in the interbank target rate (see Figure 2.6). To keep the target rate in the midpoint of the corridor, the central bank would have to conduct a contractionary *fine-tuning operation*, depicted by the leftward shift of the reserve supply in Figure 2.6.

2.2.2. Reserve Requirements

As noted above, reserve requirements are deposits that banks have to hold with the central bank. The amount of required reserves is typically measured as a percentage of certain bank liabilities – usually non-bank deposits. If the central bank imposes a reserve ratio r, required reserves become

$$RR = rD \tag{2.17}$$

where D depicts the deposit base. Now this affects the reserve demand in our corridor framework, because whenever a bank's actual reserve holdings fall below RR at the end of the day, it has to borrow the difference at the penalty rate i_b. The probability of being short of reserves is thus given by $1 - F\left(\frac{R}{n} - RR\right)$. Similarly, if we assume that only reserves above the RR threshold receive the deposit rate i_d, the corresponding probability of having to place excess reserves in the deposit facility is given by $F\left(\frac{R}{n} - RR\right)$. Accordingly, banks' optimality condition under reserve requirements changes to

$$F\left(\frac{R}{n} - RR\right) = \frac{i_b - i}{i_b - i_d}, \tag{2.18}$$

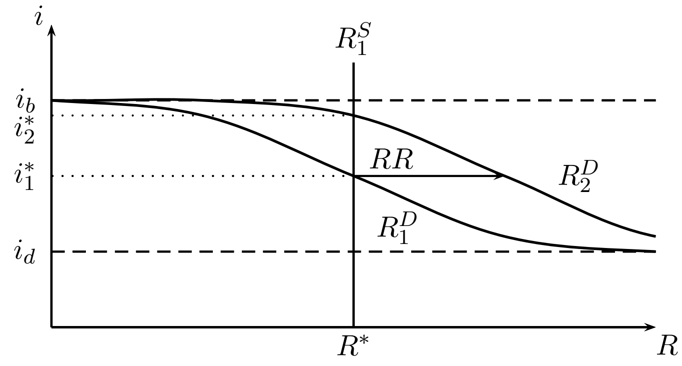

Figure 2.7.: Reserve requirements

implying that any increase in reserve requirements causes a rightward shift of the reserve demand schedule such that the higher demand for reserves is reflected in a higher market price for reserves ($i_2 > i_1$ in Figure 2.7).

In principal, this means that central banks could implement monetary policy through changes in reserve ratios. Ultimately, however, using changes in reserve requirements as a monetary policy tool rests on the presumption that central banks can, via the money multiplier, affect credit and monetary aggregates (Keynes, 1930). But with the increasing instability of the money multiplier since the 1980s, reserve requirements no longer play such a role.

Another argument for minimum reserve requirements is to use them as 'built-in stabilizers' to make the monetary system less harmful to exogenous shocks (Richter, 1968; Baltensperger, 1982; Bindseil, 2014). This should facilitate monetary targeting and thus reduce the volatility of interest rates. However, Brunner and Lown (1993) have shown that lowering reserve requirements from a low level (as currently prevailing in most central banks) to zero would have no substantial effect on money market volatility. Whether reserve requirements are really useful to achieve the ultimate target of price stability is also questioned (Siegel, 1981; Baltensperger, 1982). Furthermore, as non-remunerated reserve requirements act as tax on the banking system, they lead to increasing credit costs. Based on these facts, most advanced central banks therefore abstain from using non-remunerated reserve requirements as a 'built-in stabilizer'.

Indeed, reserve requirements are nowadays mostly used to create a structural liquidity shortage and increase the refinancing needs of the banking system vis-à-vis the central bank. In addition, banks usually have to fulfill their reserve requirements not daily, but on average over a given maintenance period. This averaging implies that any divergence from reserve requirements during the maintenance period has no effect on overnight rates as long as banks expect it to be reversed before the end of the maintenance period. Thereby, reserve requirements with averaging act as a liquidity cushion against exogenous shocks to banks' liquidity needs, which increases the interest-elasticity of the reserve demand, such that changes in supply have a smaller effect on interest rates. This *buffer function* thus stabilizes the volatility of money market rates and enables the central bank to adopt a 'non-interventionist' stance in the money market even under a symmetric corridor regime (Bundesbank, 1995).

It should be noticed, however, that the higher interest-elasticity of the reserve demand depends on the remaining number of days in the maintenance period. In fact, reserve demand might become extremely inelastic at the last day of the maintenance period, as banks cannot trade more (or less) reserves today for less (or more) reserves tomorrow (see, e.g., Whitesell, 2006; Bernhardsen and Kloster, 2010). Therefore, many central banks have introduced measures to prevent large interest rate fluctuations at the last days of a reserve maintenance period (e.g. they conduct regular fine-tuning operations or they allow banks to shift limited reserve surpluses or deficit into the next maintenance period).

2.2.3. Stigma Effect

A potential obstacle to a well-functioning corridor system arises if there is a *stigma cost* associated with the central bank's borrowing facility. Based on the existence of asymmetric information, such stigma can occur as an equilibrium phenomenon if market participants infer financial conditions from banks' recourse to the borrowing facility (Philippon and Skreta, 2012; Ennis and Weinberg, 2013). This might be especially problematic during crisis times, since informational frictions tend to move in a procyclical fashion.

In fact, despite several measures enacted by the Fed to encourage lending through the borrowing facility, banks scarcely accessed the borrowing facility during the 2007-2008 financial crisis (Armantier et al., 2015). The reason is that banks were concerned that if their recourse to the borrowing facility became known, market participants might have interpreted this as a sign of financial weakness, which would have them cut off from private funding sources.[15] In line with this argument, Armantier et al. (2015) find that

[15] Although most central banks offer an anonymous access to their borrowing facilities, information about the borrowers' identities have been leaked by the media on several occasions. Market agents can also

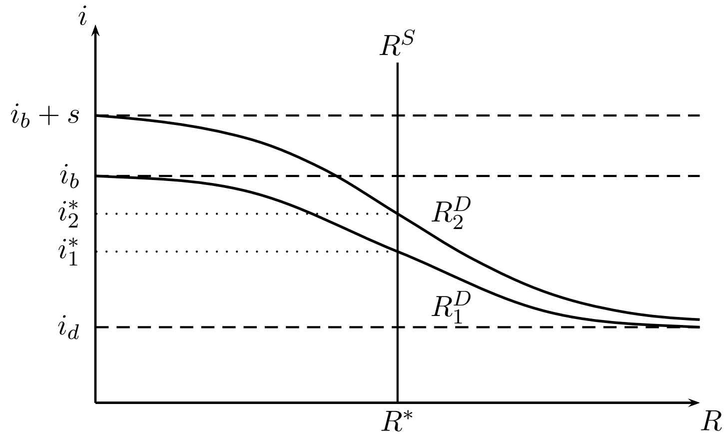

Figure 2.8.: Stigma effect

in the US the stigma premium relative to alternative funding sources amounted to about 44 basis points between December 2007 and September 2008. Hence, the stigma effect imposed substantial costs on US banks, thereby effectively inhibiting the Fed's role as a *lender of last resort* for the banking system.

Importantly, this also negatively affects monetary policy implementation under a corridor framework, because the upper bound of the corridor becomes "leaky" if banks are willing to pay a stigma premium on interbank rates (Kahn, 2010). To see this, consider Figure 2.8: if we assume that the stigma costs s are proportional to the amounts obtained through the borrowing facility, then the perceived costs of borrowing from the central bank become $i_b + s$. If we further assume that interbank borrowing is *not* subject to this stigma, then the interbank rate is still i. As a corollary, the optimality condition ⟨2.15⟩ becomes:

$$F\left(\frac{R}{n}\right) = \frac{i_b + s - i}{i_b + s - i_d}. \qquad \langle 2.19\rangle$$

This implies that the upper bound of the corridor shifts upwards, stretching the reserve demand curve from above, and yielding a higher equilibrium interbank rate i_2^*. Now, in principle, two options are feasible to restore symmetry. Either the central bank increases the aggregate reserve supply via expansionary open-market operations, or it mitigates the stigma by ensuring absolute anonymity in its borrowing facility.

make educated guesses about the use of the borrowing facility based on a bank's interbank market activity. That means that, even though central banks do not disclose the identities of their borrowers, the sufficient condition for a stigma effect seems to hold in practice.

The Fed's Term Auction Facility In December 2007, the Fed established the so-called *Term Auction Facility* (TAF). Under this facility, the Fed temporarily auctioned collateralized loans with maturities of 28 and 84 days against the same collateral as eligible under the discount window. Besides directly accommodating the elevated funding pressures in the US money market, a major objective of the program was to eliminate any perception of stigma associated with the Fed's discount window.[16] To achieve this, the TAF's borrowing rates were set through a competitive auction format subject to a minimum bid rate, rather than just posting a fixed rate (as in the discount window). Moreover, while discount window loans are credited at the same day, funds obtained through the TAF were only credited with a delay of three days. In addition, the Fed capped the total amount of reserves that it supplied via TAF, but also limited the maximum allotment to any individual bank to 10% of the total. Thereby, the Fed ensured that an oversubscribed TAF auction would have at least ten winners (Armantier et al., 2008).

Hence, the way TAF was implemented meant that banks approached the Fed collectively, rather than individually, and funds were allocated at a competitive rate with a delay of three days, rather than immediately at a penalty rate set by the Fed. All these features contributed to the success of the TAF in mitigating potential stigma effects (Armantier et al., 2015). Thus, most empirical evidence suggests that TAF had a strong effect in unsecured money markets, primarily through relieving banks' short-term funding concerns (Wu, 2008).

2.2.4. Floor System

The Fed, the ECB and many other major central banks are de facto operating *floor systems* since the end of 2008.[17] In a floor system the standing facility rates i_b and i_d are still in place, but the money market is saturated with reserves.

This is graphically illustrated in Figure 2.9. The reserve supply R^S has to shift so far to the right that it intersects with the horizontal part of the reserve demand schedule R^D (see, e.g., Goodfriend, 2002; Keister et al., 2008). Consequently, the interbank rate drops to the deposit rate i_d, such that the opportunity costs of excess reserves holdings vanish. Similarly, the policy rate equals the central bank's deposit rate ($i_2^* = i_d$), while reserve demand shocks cease to have an effect on interest rates. Therefore, the central

[16] As noted above, the Fed calls its marginal borrowing facility 'discount window'.
[17] Officially, however, only a few central banks acknowledged this change in their policy frameworks.

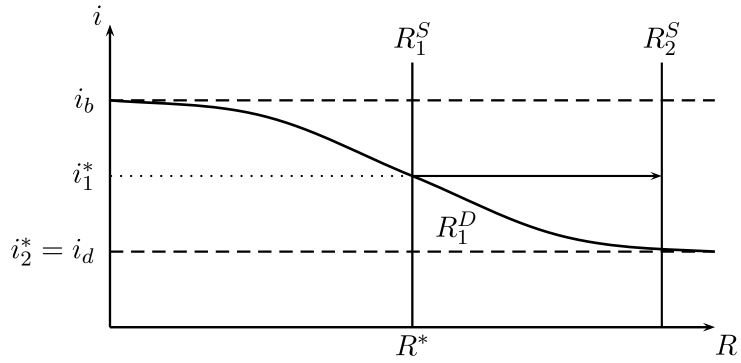

Figure 2.9.: Floor system

bank is perfectly able to control money market rates without the need of fine-tuning operations.

However, probably the main advantage of a floor system is that open-market operations and interest on reserves become two *independent* monetary policy tools. This arises because the central bank can increase the reserve supply without pushing the money market rate below its policy rate. In times of financial stress, for instance, the central bank might want to increase the reserve supply, either as an intended policy or as the byproduct of different kinds of asset purchases, but without conflicting its goal of steering the money market rate close to the policy rate. Hence, in a floor system, central banks can maintain clarity about their monetary policy stance even in an environment of large excess reserves (Bernhardsen and Kloster, 2010).[18]

Recently, Cúrdia and Woodford (2011) have shown that if there are inefficiencies in the financial intermediation process that give rise to a positive reserve demand, then this inefficiency should be erased by implementing a floor system. However, such beneficial effects must be weighted against the potential disadvantages that may arise when the central bank assumes the role of the interbank market.

As argued by Berentsen et al. (2013), a floor system is *not* optimal if the central bank is running a deficit, because then the interest on reserves have to be financed by distortionary taxation levied upon the household sector. Under such conditions, the central bank should instead implement a symmetric corridor system in order to earn a positive interest rate margin and to reduce the costs of taxation. Those policy implications can be

[18]While largely irrelevant at the zero lower bound of the policy rate, the ability to pay interest on reserves becomes an important tool when the central bank wants to tighten its stance in an environment of large excess reserves. By paying interest on reserves, tightening can be achieved without draining all excess reserves from the banking system. For a more detailed discussion of exit options, see chapter 10.2.

questioned, however. First, it seems questionable whether the comparatively small margins that central banks earn under standard corridor systems are relevant from a fiscal perspective. Second, it seems likely that banks would pass the higher refinancing costs resulting from corridor systems on to households. Thus, from a welfare perspective, one would have to compare the negative effects of higher taxation under a floor system with the higher intermediation costs under a corridor system. As Berentsen et al. (2013) abstract from this analysis, their conclusion appears to be highly model-dependent.

A more convincing argument against a floor system is that it discourages private interbank trading. This might be welfare-decreasing, because high interbank trading can improve financial stability through active monitoring of interbank risks (see, e.g., Rochet and Tirole, 1996; Furfine, 2001; Hoerova and Monnet, 2016).[19] Given information asymmetries between borrowers and lenders, a bank will lend unsecured only if it is convinced that the borrower is safe. Therefore, potential borrowers must accept that they are monitored by lenders. In theory, this will lead to sounder business models and a banking system that is more resilient to financial crises. To that end, there seems to be some significant benefits from implementing a relatively wide corridor and having a decentralized unsecured interbank market as a means to allocate liquidity in the banking system (Bräuning and Fecht, 2012).

In practice, however, one has to acknowledge that interbank trading takes place at the very short end of the yield curve (mostly overnight). Thus, the only concern of an interbank lender is that its counterparty will not default during the next couple of days. Then, however, is seems questionable whether lenders really have an incentive to put enough effort in monitoring their borrowers' long-term solvency, at least in such a way that financial stability improves sufficiently. Although existing empirical evidence suggests that interbank markets do serve as a discipline device against excessive risk taking (King, 2008), the financial crisis of 2008-09 should be a reminder not to overstate this mechanism.

Finally, the fact that central banks made positive experiences with floor systems in stressed conditions does not necessarily imply that they should adhere to this system under normal conditions. Therefore, the benefits of an active interbank market must be weighted against the costs of more volatile money market rates. As the latter was not really an issue in pre-crisis times, at least for the major central banks, it seems plausible to return to a positive corridor system in normal times.

[19]This result rests on the assumption that decentralized markets have an advantage in monitoring (credit) risks compared to centralized ones (Malamud and Rostek, 2012).

2.3. Monetary Policy Implementation in the Financial Crisis

2.3.1. The Euro Money Market Since August 2007

On the 9th of August 2007, when the French commercial bank PNB Paribas blocked the withdrawals of three hedge funds due to what it called "a complete evaporation of liquidity" (Elliott, 2012), the tensions that originated in the US subprime mortgage market finally reached Europe. The stress on euro money markets intensified in the following weeks as rumors about substantial exposures of European banks towards 'toxic' subprime loans affected their ability to obtain liquidity in the US dollar market, which subsequently led to a sharp increase in euro money market rates.[20] The main reasons why banks refused to lend especially in the unsecured interbank market were liquidity and solvency concerns that resulted from asymmetric information and heightened uncertainty (see, e.g., Eisenschmidt and Tapking, 2009; Frutos et al., 2016.)

This is also reflected in the spread between the unsecured euro interbank deposit rate (Euribor) and the euro overnight indexed swap rate (OIS) of the same maturity. Since the OIS rate represents the fixed rate that banks are willing to pay in exchange for receiving the average overnight rate for the duration of the swap contract, it reflects the same credit and liquidity risk premia as the overnight rate. But as swap partners only exchange net interest differentials at maturity but not the principal, OIS contracts carry negligible default and liquidity premia. Thus, Euribor-OIS spread serves as an indication for credit and funding risks in the European interbank market.

By using this spread, one can clearly identify some periods of severe stress on the European money market (see Figure 2.10). First, the emergence of the initial interbank turbulence is displayed as a level shift in the Euribor-OIS spread from around 5 basis points to more than 60 basis points in August 2007. And although the spread stood at more than 90 basis points by the end of that year, money market conditions broadly stabilized at this level until September 2008.

Second, on September 15, 2008, the failure of Lehman Brothers caused major disturbances on financial markets, which ultimately also affected the real economy. While the Euribor-OIS spread spiked at almost 200 basis points in October 2008, GDP, inflation, and asset prices contracted sharply throughout the following year (see Figures 2.10 and 2.11, respectively). To counter those developments, the ECB aggressively changed its li-

[20] The model of the interbank market by Heider et al. (2015) provides a very insightful analysis of the developments in global interbank markets prior to and during the 2007-09 financial crisis. The remarks of this section, however, are mainly based on ECB (2009) and Bundesbank (2011).

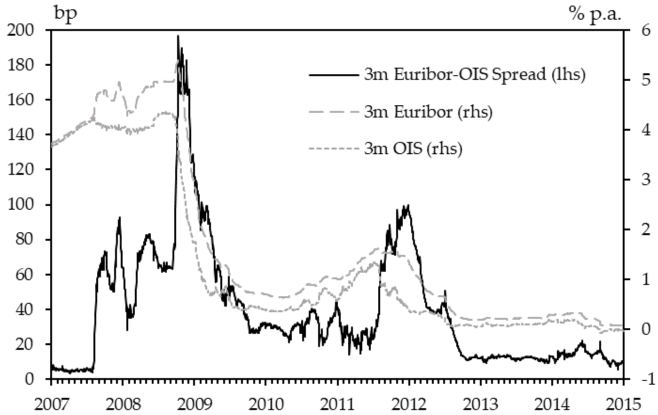

Figure 2.10.: 3-month Euribor-OIS spread ◇ *Source:* European Banking Federation, Datastream

quidity management and initiated a series of substantial policy rate cuts (see the lower right panel in Figure 2.5). Thereby, the ECB avoided a complete stall of liquidity for the banking system. In fact, since this time the ECB has assumed the role of the interbank market and fully satisfied the liquidity demand of the banking sector.

Following the mild recovery that had started in the second half of 2009, tensions began to re-emerge during the course of 2010, when markets started to question the solvency of some euro area periphery countries. The elevated risk premia on euro area government bonds (see the lower left panel in Figure 2.11) as well as the sharp deterioration in market liquidity prompted the ECB to introduce its Securities Markets Program (SMP) in May 2010. The aim of this program was to address the alleged malfunctioning of security markets and to restore an appropriate monetary policy transmission mechanism (ECB, 2010). Nevertheless, the Euribor-OIS spread widened again as the sovereign debt crisis intensified in the second half of 2011. This time, the ECB responded by providing two supplementary long-term refinancing operations (LTROs) with a maximum maturity of three years. A more detailed analysis of these measures is given in section 2.3.3. Before that, however, the next section sheds further light on the ECB's response to the pre-Lehman turmoil.

2.3.2. Pre-Lehman Policy Measures

In response to the tensions that arose in euro money markets in August 2007, the ECB changed the allotment pattern in its main refinancing operations. Prior to the crisis, the

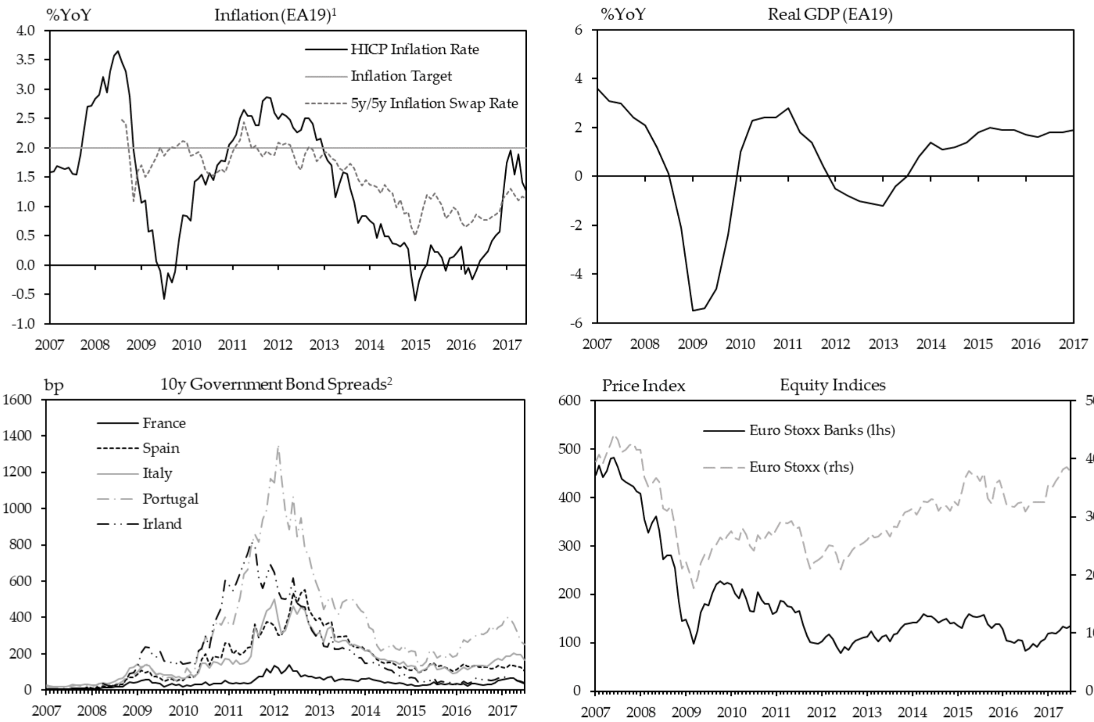

Figure 2.11.: Selected euro area macro variables during the crisis ⋄ [1]The 5y/5y inflation swap rate in the upper left panel measures the market expectation of the average five year inflation in five years ⋄ [2]10-year government bond spreads in the lower left panel depict the yield differences with respect to 10y German government bonds ⋄ *Source:* Eurostat, Datastream

ECB in its weekly main refinancing operations (MROs) had allotted a fixed amount of reserves using a variable rate tender procedure subject to a minimum bid rate. This pattern had proven to be quite successful in steering the money market rate close to the minimum bid rate (see the lower right panel in Figure 2.5), and it allowed the banking system to smoothly fulfill its reserve requirements over the course of the maintenance period.

Frontloading of Reserves Requirements Starting in August 2007, however, the rising uncertainty on interbank markets induced a higher and more volatile demand for liquidity from the banking sector. In particular, banks tried to fulfill their reserve requirements at an early stage, because they were uncertain whether they would still be able to access the money market at the end of the period. Hence, the ECB adapted to these changing money market conditions by providing more ample liquidity at the beginning of each maintenance period, while the liquidity supply was decreased towards the end (such that the average net liquidity remained unchanged, see also Figure 2.12).[21] Nevertheless, the resulting 'frontloading' of reserves provided the banks with additional security and helped the ECB to contain the average spread between the EONIA and the minimum bid rate at about 0.7 basis points in the pre-Lehman phase (7 August 2009 to 12 September 2008).[22]

Supplementary LTROs As a second measure, in August 2007 the ECB began to conduct supplementary liquidity-providing LTROs with a maturity of three months, which were complemented by additional six month LTROs in March 2008. Through the regular provision of those LTROs, the Eurosystem had provided more than €620 billion of reserves to the banking system by the end of 2008. Since the banks increasingly substituted the MROs with the LTROs, the average maturity of the Eurosystem's refinancing operations rose substantially, but the aggregate liquidity supply did not increase until September 2008.

US Dollar Swap Lines In December 2007, the ECB and the Federal Reserve (in combination with the Fed's Term Auction Facility) established a dollar swap line to address the difficulties faced by euro area banks to access the US funding market (Kwan, 2009).[23]

[21] During this episode, the ECB also conducted various fine-tuning operations.

[22] At the same time, however, the spread's volatility increased substantially (its standard deviation doubled to 12 basis points compared to the previous year). This reflected the ECB's increasing difficulties in estimating the precise liquidity needs of the banking system.

[23] Subsequently, the dollar swap lines were extended to the following central banks: the Swiss National Bank, the Reserve Bank of Australia, the Banco Central do Brasil, the Bank of Canada, Danmarks Natio-

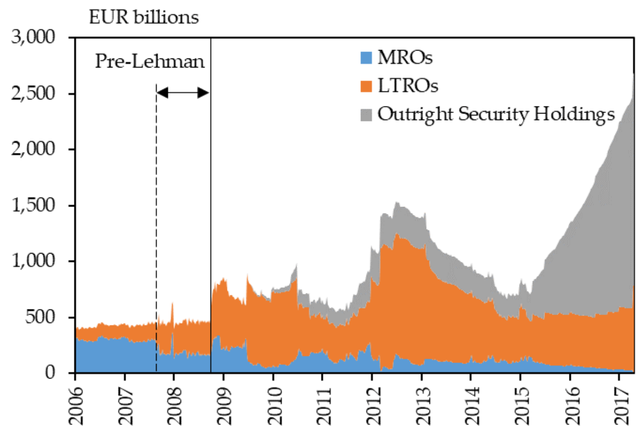

Figure 2.12.: Liquidity providing asset components of the ECB's balance sheet ⋄ The dashed vertical line depicts the beginning of the money market tensions in August 2007 ⋄ The solid vertical line depicts the last trading day before the failure of Lehman Brothers (12 September 2008) *Source:* ECB

Through this swap line, the outstanding amount of US dollars provided by the Eurosystem peaked at around $300 billion by the end of 2008, which proved to be very successful in accommodating the need for dollar refinancing of the euro area banking sector.

2.3.3. Post-Lehman Policy Measures

After the bankruptcy of Lehman Brothers on 15 September 2008, global money markets experienced a complete gridlock, when banks – due to mounting counterparty risks – started to hoard liquidity instead of lending it out on the interbank market (Heider et al., 2015). Apart from the peaking Euribor-OIS spread (see Figure 2.10), this sudden shortfall of funding liquidity on the money market is also mirrored in the rising interest rates that banks were willing to pay in the Eurosystem's refinancing operations (left panel of Figure 2.13) as well as the rising number of banks that participated in these operations (right panel of Figure 2.13). Collectively, the monetary policy measures in response to the failure of Lehman Brothers are sometimes referred to as the ECB's *enhanced credit support* (Trichet, 2009). The following paragraph reviews some of its key measures.

nalbank, the Bank of England, the Bank of Japan, the Bank of Korea, the Banco de Mexico, the Reserve Bank of New Zealand, Norges Bank, the Monetary Authority of Singapore, and the Sveriges Riksbank. The Eurosystem's average share accounted for about 50% of these swap lines. All arrangements were terminated on February 1, 2010. For further details, see Board of Governors of the Federal Reserve System (2017).

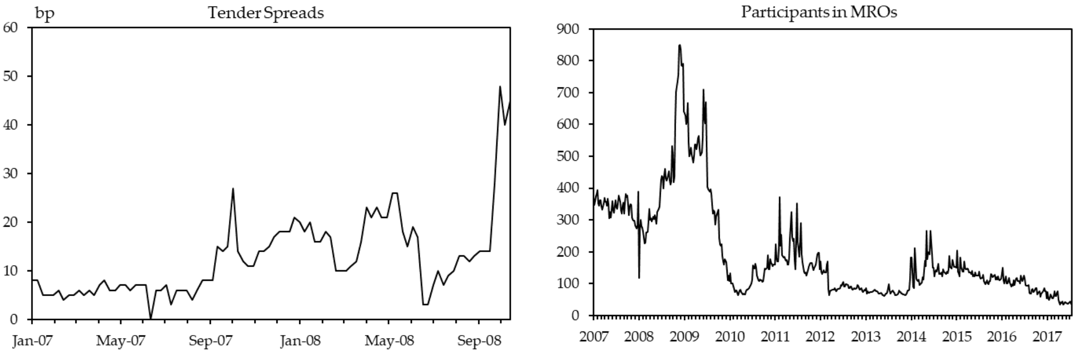

Figure 2.13.: Bidding activity in ECB liquidity operations ⋄ The left panel depicts the spread between the marginal rate and the minimum bid rate until the introduction of FRFA ⋄ The right panel depicts the number of participants in the Eurosystem's main refinancing operations ⋄ *Source:* ECB, Datastream

Fixed Rate Full Allotment (FRFA) Against this background, the ECB announced on 8 October 2008 that it was going to switch the allotment procedure in its MROs to a fixed rate tender with full allotment. This meant that all bids were fully satisfied at the fixed MRO rate, such that any previously observed tender spreads were eliminated.[24] In addition, the ECB embarked on a series of aggressive policy rate cuts. Starting in mid-October 2008, it reduced its key policy rate from 4,25% to 1% as of May 2009. Simultaneously, the ECB reduced the standing facilities corridor from 200 to 100 basis points around the interest rate on the main refinancing operations.[25]

Expansion of Collateral As a second measure, the Governing Council decided on 15 October 2008 to expand the list of assets eligible as collateral in its refinancing operations. Specifically, this was done by lowering the rating threshold for marketable and non-marketable securities from A- to BBB- (except for ABS, for which the A- rating remained unchanged). The aim of this measure was to ensure that the availability of collateral did not become a binding constraint after the introduction of the fixed-rate full allotment procedure. And although haircuts were increased conditional on the asset quality, the ECB estimates that about 7% of the total amount of marketable assets and a 'significant amount of non-marketable assets' became eligible when the credit standards were lowered to the investment grade threshold (ECB, 2009). In this context, Hilberg and Hol-

[24]Subsequently, the FRFA procedure was also applied to the regularly and supplementary LTROs, as well as to the swap operations in US dollars.

[25]As of January 2009, the corridor was widened again to 200 basis points, but only to be gradually lowered to 50 basis points in the subsequent years. Since March 2016, the corridor has now been standing at 75 basis points, i.e. 125 basis points below its pre-crisis average.

lmayr (2013) show in a New-Keynesian model with a heterogeneous banking sector that if the interbank market is drying up, decreasing the haircut on central bank collateral is a suitable tool to boost interbank lending and output, especially when the conventional policy rate is already close to zero (see also Ashcraft et al., 2011).

Further Foreign Exchange Swap Lines Based on the positive experience with the US dollar swap line that had been implemented in December 2007, the Eurosystem in October 2008 established a similar agreement with the Swiss National Bank (SNB) to counter the upward pressure on Swiss money market rates and to address the funding needs of euro area banks in Swiss francs.

Further LTROs and CBPP In line with the supplementary 6-month LTROs that had been implemented already in the pre-Lehman episode, the ECB in June 2009 decided to conduct a series of additional 12-month LTROs. In contrast to the 6-month LTROs, however, the 12-month LTROs were conducted as fixed rate tenders with full allotment. In addition, the ECB initiated the so-called *Covered Bond Purchase Program* (CBPP) to stabilize the market for those securities.[26] The primary goal of those measures was to support banks' funding conditions in order to promote their contracting credit supply.

In terms of liquidity provision, however, these measures were marginalized by the two 3-year LTROs that were implemented in December 2011 and February 2012, respectively (again as fixed rate tenders with full allotment; cf. ECB, 2011). With both 3-year LTROs, the ECB injected about €520 billion of net reserves (see Figure 2.12).[27] Given this massive amount of excess liquidity in the financial system, money market rates approached the ECB's deposit rate, and the Euribor-OIS spread ultimately stabilized at about 12 basis points, i.e. slightly above its pre-crisis level (see Figure 2.10). It thus seems that the 3-year LTROs, by compressing the Euribor-OIS spread, have succeeded in reducing the elevated counterparty risks that had re-emerged due to the European sovereign debt crisis, and thereby significantly eased banks' funding conditions (Darracq-Paries and De Santis, 2013).

On the other hand, the massive recourse to the ECB's deposit facility displayed in Figure 2.14 indicates that the banks in the euro area rather hoarded the liquidity rather

[26] With this first CBPP (CBPP1), the ECB purchased euro area covered bonds for a nominal value of €60 billion over the course of one year. In November 2011, it initiated CBPP2 for a total amount of €40 billion, which was followed by CBPP3 in October 2014 with an intended term of two years.

[27] The total size of the two 3-year LTROs reached about €1 trillion, whereby €489 billion were allotted to 523 bidders in the first LTRO and €530 billion to 800 bidders in the second LTRO. However, the net liquidity injection reached 'only' about €520 billion, as the other half was used to refinance maturing short-term credit.

than increasing their lending to the private sector. This is also reflected in the fact that the massive expansion of the ECB's balance sheet did not sufficiently cushion the drop in the money multiplier, also because the credit demand of firms and households in the euro area remained subdued due to the ongoing deleveraging process in the distressed peripheral countries. Figures 2.12 and 2.14 also show that banks used the option to repay the 3-year LTROs after one year, which thus withdrew some of the excess market liquidity. Finally, however, massive liquidity has been injected again through the ECB's public sector asset purchase program (PSPP), the effects of which are examined in Part II of this thesis.

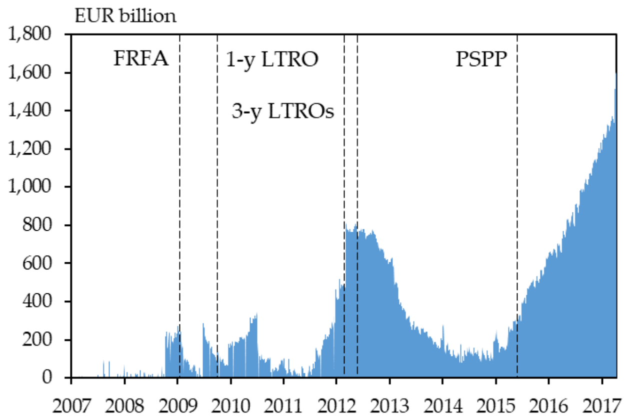

Figure 2.14.: Excess liquidity in the euro area ⋄ Excess liquidity is defined as MFIs recourse to the deposit facility net of marginal lending facility plus current account holdings net of reserve requirements ⋄ *Source:* ECB

Risks Associated with the 3-year LTROs Acharya and Steffen (2015) argue that the 3-year LTROs created an incentive for European banks to 'borrow low-for-long' and to invest the proceeds into high yielding euro area peripheral bonds of the same maturity. The operations thus constituted the 'greatest' carry trade ever and arguably a subtle way of monetary financing of government debt in the midst of the sovereign debt crisis. In this respect, Figure 2.15 shows that the periphery countries' share in the Eurosystem's refinancing operations has in fact significantly increased during the second half of 2010.

In turn, shortly after the announcement of the 3-y LTROs, Spain managed to place €6 billion in government debt even though only €3.5 billion were envisaged ex-ante. Furthermore, Acharya and Steffen (2015) show that especially risky banks, i.e. big and undercapitalized institutions with high short-term leverage and high loan-to-asset va-

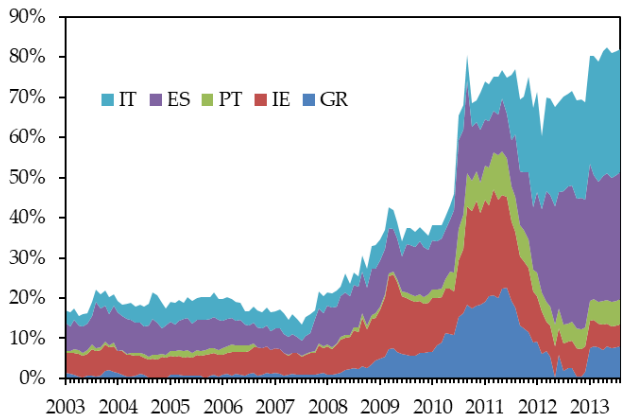

Figure 2.15.: Periphery countries' share in Eurosystem's lending operations (MRO & LTRO) ⋄ *Source:* Bruegel Dataset of Eurosystem Lending Operations

lues, had an incentive to shift into this carry trade because regulation attached zero risk weights to government bonds. In that way, the ECB's LTROs supported a profitable carry trade likely to have helped bank recapitalization. Accordingly, Italian and Spanish banks increased their holdings of national government bonds with maturities up to three years by €28.6 billion and €6 billion, respectively, while core-European banks simultaneously decreased their holdings of peripheral sovereign bonds in absolute terms. In this way, the two 3-year LTROs led to an increasing *home bias* of European banks and further contributed to the interconnectedness of the banking sector with national sovereign debt markets, which may seriously undermine financial stability (Shambaugh, 2012).

Examining the yield curves for euro area government bonds broadly confirms this picture. On the one hand, the 3-year LTROs induced a downward shift of the yield curves for both high-rated as well as lower-rated sovereigns. On the other hand, the positive impact was especially pronounced for the latter. In addition to the level effect, the yield curves of those sovereigns experienced a substantial drop in the 3-year maturity spectrum (see the right panel of Figure 2.16).

2.3.4. Concluding Remarks

Up to this point, it can be noted that the ECB's monetary policy framework, and, after some modifications, also the Fed's framework proved effective in containing the recurring money market stress since August 2007. In the aftermath of the Lehman collapse,

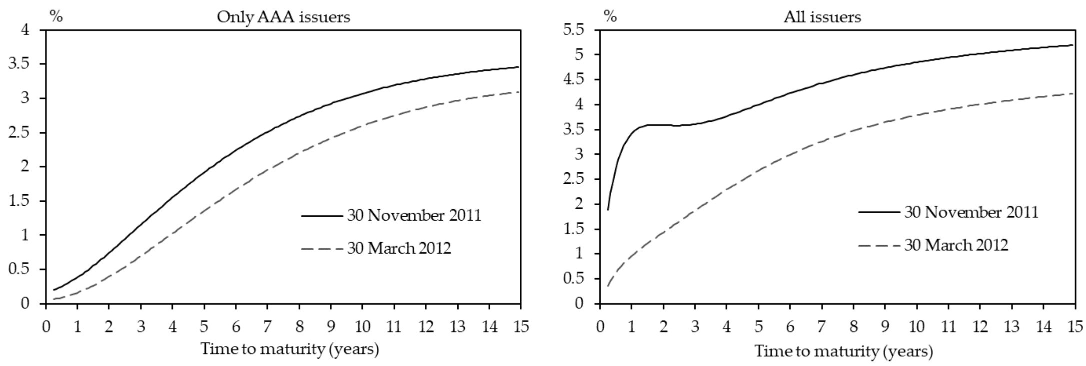

Figure 2.16.: Euro area government yield curves ◇ The left panel includes Germany, Liechtenstein, Luxembourg, and Netherlands ◇ The right panel includes all euro area countries ◇ *Source:* Eurostat, ECB

this was mainly achieved by replacing large parts of the malfunctioning interbank market with central bank intermediation. In this sense, monetary policy's enhanced liquidity provision has contributed to the interruption of an 'adverse spiral' that may have easily unfolded from the financial market tensions. Moreover, since the liquidity management measures enabled distressed banks to cover their short-term funding gaps, they mitigated the banks' immediate pressure to cut down on lending (see also section 7 of this thesis). Thus, Rajan argues that "[b]y lending long term without asking too many questions of the collateral they received, by buying assets beyond usual limits, and by focusing on repairing markets, [central bankers] restored liquidity to a world financial system that would otherwise have been insolvent based on prevailing asset prices. In this matter, central bankers are deservedly heroes in a world that has precious few of them" (Rajan, 2013, p. 5).

In the longer run, however, these positive effects of unconventional monetary operations might increasingly dissipate – especially if the enhanced credit support measures contribute to the postponement of necessary structural reforms in the banking sector.

3. Conventional Monetary Policy in the New Keynesian Model

3.1. Baseline New Keynesian Model

The *New Keynesian model* (NKM) serves as the standard workhorse model in today's monetary policy analysis. It belongs to the class of *Dynamic General Equilibrium* models (DSGE) with a strong emphasis on the role of microfoundations. More specifically, the NK model includes intertemporally optimizing agents with rational expectations who adjust their consumption and employment paths to a sequence of stochastic shocks. With these features, the NK framework resembles the classical *Real Business Cycle* model (RBC),[1] but it relaxes the assumption of perfect competition and flexible prices. Besides the assumption of *sticky prices* – which has the important implication that monetary policy becomes able to influence real variables through the *interest rate channel* – the baseline NK model in essence assumes perfectly flexible financial markets.

In fact, monetary policy is characterized by an interest rate rule for the very short-end of the yield curve, while money markets and financial institutions are typically not even modeled.[2] Therefore, long-term interest rates have no effect on the macroeconomy, nor do asset prices or risk premia. As will be discussed later, this is the reason why the baseline NK model cannot account for most of the transmission channels of unconventional monetary policies. Before that, however, the next paragraph briefly illustrates the structure of the baseline NK model. Later on, this framework will be enlarged to incorporate financial frictions, which also introduces a role for unconventional monetary policy.

[1]The seminal papers in the RBC literature include Kydland and Prescott (1982); Black (1982); Long and Plosser (1983); and Prescott (1986).

[2]Recently, the baseline NK model has been enlarged to include financial markets subject to various frictions; see, amongst others, Goodfriend and McCallum (2007); Canzoneri et al. (2008); Cúrdia and Woodford (2010); and Gertler and Karadi (2011).

3.1.1. Households

In the NK baseline specification, the representative household maximizes expected utility from consumption, C_t, over disutility from hours worked, N_t. With the standard Cobb-Douglas utility function,

$$U(C_t, N_T) = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi}, \tag{3.1}$$

the households maximization problem reads

$$\max_{C_t, N_t, B_t,} \mathrm{E}_t \sum_{t=0}^{\infty} \beta^t U(C_t, N_t) \tag{3.2}$$

subject to the flow budget constraint

$$\int_0^1 P_{it} C_{it} \mathsf{d}i + Q_t B_t \leq B_{t-1} + W_t N_t + T_t \tag{3.3}$$

where B_t denotes a one-period zero-coupon bond with price $Q_t = \frac{1}{1+i_t}$, W_t the nominal hourly wage, and T_t are net transfers.[3] Specifically, the household can choose to consume from a continuum of imperfect substitutes where the consumption basket is given by the so-called *Dixit-Stiglitz Aggregator*,

$$C_t \equiv \left(\int_0^1 C_{it}^{\frac{\epsilon-1}{\epsilon}} \mathsf{d}i \right)^{\frac{\epsilon}{\epsilon-1}}, \tag{3.4}$$

where C_{it} denotes the quantity of a good i consumed in period t and the parameter ϵ measures the elasticity of substitution between goods. In other words, for $\epsilon = 0$ ($\epsilon = \infty$) goods are complements (perfect substitutes), whereas for $\epsilon \in (0, \infty)$ households have a *love for variety*.

Thus, in a first step, the household has to choose a consumption bundle that maximizes total consumption subject to a given expenditure constraint $\bar{Z}_t$. As shown in the

[3]The exposition of the baseline NK model in this section relies heavily on Clarida et al. (1999); Galí (2008); and Bergholt (2012), but can also be found in other publications.

appendix B.2, this implies that the demand function for each good i takes the form of

$$C_{jt} = \left(\frac{P_{jt}}{P_t}\right)^{-\epsilon} C_t \quad \forall i, j \tag{3.5}$$

where the aggregate price index given by

$$P_t \equiv \left(\int_0^1 P_{it}^{1-\epsilon} \mathsf{d}i\right)^{\frac{1}{1-\epsilon}}. \tag{3.6}$$

In a second step, for given P_{it}, P_t and the respective consumption profiles, the household has to derive the optimal allocation of consumption and labor. Assuming zero net transfers, the first-order conditions of the maximization problem ⟨3.2⟩ are given by:

$$\frac{\partial \mathcal{L}}{\partial C_t} = C_t^{-\sigma} - \lambda_t P_t = 0 \tag{3.7}$$

$$\frac{\partial \mathcal{L}}{\partial N_t} = N_t^{\varphi} - \lambda_t W_t = 0 \tag{3.8}$$

$$\frac{\partial \mathcal{L}}{\partial B_t} = -\lambda_t Q_t + \beta \mathrm{E}_t\{\lambda_{t+1}\} = 0 \tag{3.9}$$

Combining ⟨B.16⟩ and ⟨B.17⟩ yields the *intra*temporal allocation of consumption and labor as

$$\frac{W_t}{P_t} = C_t^{\sigma} N_t^{\varphi}. \tag{3.10}$$

It indicates how to optimally allocate consumption and hours worked within a given period. The intuition is that the marginal disutility from labor has to be rewarded with a higher real wage such that perfect compensation can be achieved through a marginal increase in consumption.

Similarly, combining ⟨B.16⟩ with ⟨B.18⟩ while exploiting the fact that $\mathrm{E}_t\{\lambda_{t+1}\} = \mathrm{E}_t\left\{\frac{C_{t+1}^{-\sigma}}{P_{t+1}}\right\}$ (which follows from forward iteration of ⟨B.16⟩), gives

$$\frac{C_t^{-\sigma}}{P_t} = \frac{\beta \mathrm{E}_t\{\lambda_{t+1}\}}{Q_t} = \frac{\beta}{Q_t} \mathrm{E}_t\left\{\frac{C_{t+1}^{-\sigma}}{P_{t+1}}\right\}$$

$$\Leftrightarrow C_t^{-\sigma} = \frac{\beta \mathrm{E}_t\{C_{t+1}^{-\sigma}\}}{Q_t} \frac{P_t}{\mathrm{E}_t\{P_{t+1}\}} = \beta \mathrm{E}_t\{C_{t+1}^{-\sigma}\}(1+i_t)\left(\mathrm{E}_t\{\frac{P_{t+1}\}}{P_t}\right)^{-1}. \tag{3.11}$$

This *inter*temporal optimality condition is also known as the *Euler equation*. It indicates that the marginal disutility from sacrificing one unit of consumption today has to be exactly compensated by the marginal expected utility from increasing consumption tomorrow, where the latter has to be corrected for the time preference and expected inflation.

Equations ⟨3.10⟩ and ⟨B.19⟩ can be log-linearized to get

$$w_t - p_t = \sigma c_t + \varphi n_t. \tag{3.12}$$

and

$$c_t = \mathrm{E}_t\{c_{t+1}\} - \frac{1}{\sigma}\left(i_t - \mathrm{E}_t\{\pi_{t+1}\} - \rho\right), \tag{3.13}$$

respectively. The log-linearized version of the *Euler equation* further highlights some key implications of the NK model. Firstly, current consumption c_t depends positively on expected consumption $\mathrm{E}_t\{c_{t+1}\}$ due to the household's consumption smoothing motive; if households expect consumption to rise, they will increase consumption in the current period in order to maintain a smooth consumption profile.

Secondly, current consumption is negatively related to the difference between the Fisher relation for the real rate, $r_t = i_t + \mathrm{E}_t\{\pi_{t+1}\}$, and the household's time preference rate ρ, determining the natural rate in these class of models ($\rho = r^n$). Hence, if the real rate equals the time preference rate ($r_t = \rho$), the household's consumption profile will be flat ($c_t = c_{t+1}$). Conversely, if the real rate is lower than the time preference rate, the household will increase current consumption at the expense of future consumption ($c_t > c_{t+1}$), and vice versa. Notice that the strength of this effect is governed by the intertemporal elasticity of substitution, $\frac{1}{\sigma}$, which equals the inverse of the household's risk aversion σ. If agents are more risk averse, they dislike volatility in consumption more strongly and are therefore less willing to perform intertemporal substitution.

3.1.2. Firms

Aggregate Inflation There is a continuum of firms indexed by $j \in [0, 1]$ and each firm produces a differentiated good $Y(j)$. Firms solely use labor as an input factor (a pure service economy) and they all employ the identical production technology

$$Y_t(j) = Z_t N_t(j)^{1-\alpha} \tag{3.14}$$

where Z_t is a common technology shock exogenously evolving according to an univariate first-order autoregressive process, $N_t(j)$ are the hours of labor firm j hires from the household sector, and $(1-\alpha)$ is the elasticity of labor with respect to output. Hence, aggregate output is defined as

$$Y_t = \left(\int_0^1 Y_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}}. \tag{3.15}$$

As noted above, the parameter ϵ represents the elasticity of substitution between the differentiated consumption goods in the eyes of the household. Since firms are assumed to operate under monopolistic competition, ϵ is bounded between $1 < \epsilon < \infty$. That is, the value of ϵ implicitly determines the mark-up over marginal costs that firms charge in the goods market. In addition to monopolistic competition, firms are subject to staggered *Calvo Pricing*. In this context, it is assumed that a stochastic fraction θ of all firms is stuck with the previous period's price, while the remaining fraction $(1-\theta)$ is able to re-optimize. The dynamics for the aggregate price level are therefore

$$P_t = \left[\theta P_{t-1}^{1-\epsilon} + (1-\theta)(P_t^*)^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}} \tag{3.16}$$

which can be log-linearized to

$$\pi_t = (1-\theta)(p_t^* - p_{t-1}). \tag{3.17}$$

Aggregate inflation emerges if firms that re-optimize in period t choose a price that differs from the last period's average price level p_{t-1}. The next step is therefore to derive the representative firm's optimal price setting behavior.

Optimal Price Setting Under the Calvo-pricing assumption, a representative firm facing the probability to re-adjust its price will choose the optimal price level P_t^* such that the market value of expected profits becomes maximized as long as the price remains effective. With θ^k as the probability that the firm has to stick to its price for the next $t+k$ periods to come, the firm's maximization problem reads

$$\max_{P_t^*} \mathrm{E}_t \sum_{k=0}^{\infty} \theta^k \left[Q_{t+k}(P_t^* Y_{t+k|t} - \Psi_{t+k}(Y_{t+k|t})) \right] \tag{3.18}$$

subject to the demand constraint

$$Y_{t+k|t} = \left(\frac{P_t^*}{P_{t+k}} \right)^{-\epsilon} C_{t+k} \tag{3.19}$$

where $Q_{t+k} \equiv \beta^k (\frac{C_{t+k}}{C_t})^{-\sigma} (\frac{P_t}{P_{t+k}})$ is the stochastic discount factor for nominal payoffs and $\Psi_{t+k}(Y_{t+k|t})$ denotes the firm's nominal cost function associated with the production level $Y_{t+k|t}$ if prices have last been reset in period t. As shown in the appendix B.2, the firm's optimal price setting rule takes the form

$$\mathrm{E}_t \sum_{k=0}^{\infty} \theta^k E_t \left[Q_{t+k} C_{t+k} \left(P_t^* - \frac{\epsilon}{\epsilon - 1} \psi_{t+k|t} \right) \right] = 0, \tag{3.20}$$

where $\psi_{t+k|t} = \Psi'_{t+k}(Y_{t+k|t})$ denotes nominal *marginal* costs, while $\frac{\epsilon}{1-\epsilon}$ is the desired or flexible price mark-up (if $\theta = 0$). By inserting $Q_{t+k} \equiv \beta^k (\frac{C_{t+k}}{C_t})^{-\sigma} (\frac{P_t}{P_{t+k}})$ and $Y_{t+k|t} = \left(\frac{P_t^*}{P_{t+k}} \right)^{-\epsilon} C_{t+k}$, equation ⟨3.20⟩ can be rearranged to express the optimal price as a weighted average of future real marginal costs

$$P_t^* = \frac{\epsilon}{\epsilon - 1} \frac{\mathrm{E}_t \sum\limits_{k=0}^{\infty} \theta^k \beta^k C_{t+k}^{1-\sigma} P_{t+k}^{\epsilon} MC_{t+k|t}^r}{\mathrm{E}_t \sum\limits_{k=0}^{\infty} \theta^k \beta^k C_{t+k}^{1-\sigma} P_{t+k}^{\epsilon-1}} \tag{3.21}$$

where real marginal costs are denoted by $MC_{t+k|t}^r = \frac{\psi_{t+k|t}}{P_{t+k}}$. Again, it should be noted that without sticky prices ($\theta = 0$), ⟨3.18⟩ collapses to a one period problem ($k = 0$) and the firm's optimal price becomes the frictionless mark-up times nominal marginal costs, i.e. $P_t^* = \frac{\epsilon}{\epsilon-1} \psi_{t+k|t}$

Log-Linearization In a zero steady-state inflation, it must hold that

$$\Pi_t = \frac{P_t^*}{P_{t-1}} = \frac{P_t^*}{P_t} = \frac{P_t^*}{P_{t+k}} = 1 \qquad \langle 3.22\rangle$$

$$Y_{t+k|t} = Y = C \qquad \langle 3.23\rangle$$

$$Q_{t+k} = \beta^k \qquad \langle 3.24\rangle$$

$$MC^r_{t+k|t} = \frac{\psi_{t|t}}{P_t} = \frac{\epsilon - 1}{\epsilon} \equiv MC^r. \qquad \langle 3.25\rangle$$

Inserting this information and performing a log-linearization of ⟨3.21⟩ by using a first-order Taylor approximation around the steady-state finally delivers[4]

$$p_t^* = \mu + (1 - \theta\beta)\mathrm{E}_t \sum_{k=0}^{\infty} \theta^k \beta^k [mc^r_{t+k|t} + p_{t+k}]. \qquad \langle 3.26\rangle$$

This equation nicely illustrates that price setting firms will choose an optimal price p_t^* which equals the steady-state desired mark-up μ plus the weighted average of current and expected nominal marginal costs,[5] where the weights imposed on future periods are proportional to (i) the discount factor β^k and (ii) the probability of the price remaining effective for k periods, i.e. θ^k.

3.1.3. Equilibrium Analysis

Goods Market Market clearing on the goods market implies that $Y_t = C_t$. The Euler equation ⟨3.13⟩ can thus be written as

$$y_t = \mathrm{E}_t\{y_{t+1}\} - \frac{1}{\sigma}\left(i_t - \mathrm{E}_t\{\pi_{t+1}\} - \rho\right). \qquad \langle 3.27\rangle$$

which gives one of the key equations: the *New Keynesian IS Curve*.

To derive the second key equation, i.e. the *New Keynesian Phillips Curve* (NKPC), the next objective is to express the optimal price ⟨3.26⟩ in terms of output instead of marginal

[4]For a thorough derivation of the log-linearization steps, see Bergholt (2012).

[5]Notice that $\mu = -mc^r$ which follows from equation ⟨3.25⟩ and $-mc^r = -\ln\frac{\epsilon-1}{\epsilon} = \ln\frac{\epsilon}{\epsilon-1} = \ln\left(1 + \frac{\epsilon-(\epsilon-1)}{\epsilon-1}\right) \approx \frac{1}{\epsilon-1} = \frac{\epsilon}{\epsilon-1} - 1 \equiv \mu$.

costs. Second, the evolution of total prices must be expressed as a combination of the optimal price setting and the price setting of firms that are unable to adjust their prices in the current period. Since *average* real marginal costs are given by the difference between the real wage and the marginal product of labor, it holds that

$$mc_t^r = (w_t - p_t) - mpn_t \tag{3.28}$$

where mpn_t denotes the (log of) the marginal product of labor, given by

$$mpn_t = \ln\left(\frac{\partial Y_t}{\partial N_t}\right) = \ln\left((1-\alpha)Z_t N_t^{-\alpha}\right) = \ln(1-\alpha) + z_t - \alpha n_t. \tag{3.29}$$

Inserting ⟨3.29⟩ into ⟨3.28⟩ yields an expression for the real marginal costs of a single firm i that sets its optimal price in t:

$$mc_{t+k|t}^r = mc_{t+k}^r - \frac{\alpha\epsilon}{1-\alpha}(p_t^* - p_{t+k}). \tag{3.30}$$

If the production function is characterized by constant returns to scale ($\alpha = 0$) such that marginal costs are independent from output, individual marginal costs will be equal to average marginal costs. Substituting ⟨3.30⟩ into the optimal price setting equation ⟨3.26⟩ yields[6]

$$\pi_t = \beta \mathrm{E}_t\{\pi_{t+1}\} + \bar{\lambda}\widehat{mc}_t^r \tag{3.31}$$

with $\bar{\lambda} = \frac{(1-\theta)(1-\beta\theta)}{\theta}\frac{1-\alpha}{1-\alpha+\alpha\epsilon}$ strictly decreasing in θ, ϵ, and α, while $\widehat{mc}_t^r$ denotes the log deviation of real marginal costs from their steady-state value.[7] Then, substituting ⟨3.12⟩ and $n_t = \frac{y_t - z_t}{1-\alpha}$ (which follows from the log-linearized production function ⟨3.14⟩) into ⟨3.28⟩, gives the real marginal costs independent of the nature of price setting,

$$mc_t^r = \left(\sigma + \frac{\varphi + \alpha}{1-\alpha}\right) y_t - \frac{1+\varphi}{1-\alpha} z_t - \ln(1-\alpha). \tag{3.32}$$

[6]See appendix B.2 for the detailed derivation steps

[7]Throughout this dissertation, small variables with a hat stand for log-linearized variables around their steady-state values.

As the steady-state marginal costs are likewise given by

$$mc^r = \left(\sigma + \frac{\varphi + \alpha}{1 - \alpha}\right) y_t^n - \frac{1 + \varphi}{1 - \alpha} z_t - \ln(1 - \alpha) \qquad \langle 3.33 \rangle$$

where y^n denotes the natural level of output under flexible prices, subtracting ⟨3.33⟩ from ⟨3.32⟩ yields

$$\widehat{mc}_t^r = mc_t^r - mc^r = \left(\sigma + \frac{\varphi + \alpha}{1 - \alpha}\right) \hat{y}_t \qquad \langle 3.34 \rangle$$

with $\hat{y}_t = y_t - y_t^n$ as the output gap. Finally, inserting ⟨3.34⟩ into ⟨3.31⟩ yields the standard notation of the *New Keynesian Phillips Curve*, i.e.

$$\pi_t = \beta \mathrm{E}_t\{\pi_{t+1}\} + \kappa \hat{y}_t \qquad \langle 3.35 \rangle$$

with $\kappa = \bar{\lambda}\left(\sigma + \frac{\varphi+\alpha}{1-\alpha}\right)$. In the same vein, the IS curve ⟨3.27⟩ can be written in output gap notation. As, by definition, shocks are absent in the steady-state, the natural output is given by

$$y_t^n = \mathrm{E}_t\{y_{t+1}^n\} - \frac{1}{\sigma}(r_t^n - \rho) \qquad \langle 3.36 \rangle$$

which can be subtracted from ⟨3.27⟩ to get

$$\hat{y}_t \equiv y_t - y_t^n = \left[\mathrm{E}_t\{y_{t+1}\} - \frac{1}{\sigma}\left(i_t - \mathrm{E}_t\{\pi_{t+1}\} - \rho\right)\right] - \left[\mathrm{E}_t\{y_{t+1}^n\} - \frac{1}{\sigma}(r_t^n - \rho)\right]$$

$$\Leftrightarrow \hat{y}_t = \mathrm{E}_t\{\hat{y}_{t+1}\} - \frac{1}{\sigma}\left(i_t - \mathrm{E}_t\{\pi_{t+1}\} - r_t^n\right). \qquad \langle 3.37 \rangle$$

Besides being positively related to its own lead, the current output gap is negatively dependent on the difference between the market real rate and the natural rate, where the latter is defined as

$$r_t^n \equiv \rho + \sigma \frac{1 + \varphi}{\sigma(1 - \alpha) + \varphi + \alpha} \mathrm{E}_t\{\Delta z_{t+1}\}. \qquad \langle 3.38 \rangle$$

Hence, the natural real rate is a function of the household's discount rate ρ and expected technology shocks. Note that this implies that in the steady-state, i.e. excluding any (technology) shocks, the natural rate equals the discount rate.

Monetary Policy and Dynamic Stability In order to close the model, the New Keynesian Phillips Curve and the New Keynesian IS Curve have to be supplemented with an interest rate rule, determining how monetary policy reacts when output and/or inflation deviates from their steady-state values. A simple example of such an ad-hoc interest rate rule is *Taylor rule* of the form

$$i_t = r_t^n + \phi_\pi \pi_t + \phi_y \hat{y}_t + \nu_t \qquad \langle 3.39 \rangle$$

where the intercept equals the natural rate, ϕ_π and ϕ_y are the weights attached to the respective policy goals, and ν_t denotes a discretionary monetary policy shock.

Substituting the Taylor rule in the IS equation ⟨3.37⟩ and plugging the resulting expression in the NKPC ⟨3.35⟩ reduces the model to a two equation system consisting of two forward-looking difference equations for π_t and $\hat{y}_t$. The system thus reads

$$\begin{bmatrix} \hat{y}_t \\ \pi_t \end{bmatrix} = A_T \begin{bmatrix} E_t\{\hat{y}_{t+1}\} \\ E_t\{\pi_{t+1}\} \end{bmatrix} + B_T(\hat{r}_t^n - \nu_t) \qquad \langle 3.40 \rangle$$

where A_T is a 2×2 coefficient matrix including both policy and non-policy variables that indicates how expectations drive current output and inflation. Similarly, B_T is a non-policy coefficient matrix that determines the effects of technology and/or monetary policy shocks. Specifically, it holds that

$$A_T \equiv \Omega \begin{bmatrix} \sigma & 1 - \beta\phi_\pi \\ \sigma\kappa & \kappa + \beta(\sigma + \phi_y) \end{bmatrix} \qquad \langle 3.41 \rangle$$

$$B_T \equiv \Omega \begin{bmatrix} 1 \\ \kappa \end{bmatrix} \qquad \langle 3.42 \rangle$$

$$\Omega \equiv \frac{1}{\sigma + \phi_y + \kappa\phi_\pi} \qquad \langle 3.43 \rangle$$

For this system to be dynamically stable, the *Blanchard-Kahn-Condition* requires that both eigenvalues of the coefficient matrix A_T have to be smaller than unity. One can show that this condition is fulfilled if

$$\kappa(\phi_\pi - 1) + (1 - \beta)\phi_y > 0. \tag{3.44}$$

This will always hold if the central bank obeys to the so-called *Taylor Principle* ($\phi_\pi > 1$), i.e. if policy rate i_t reacts overproportionally to deviations of inflation from its steady-state value (see, e.g., Woodford, 2003; Galí, 2008).

Financial Markets As noted above, the baseline New Keynesian model assumes perfect financial markets. Therefore, it is consistent to consider only one financial asset – the risk-less government bond B_t – while risky assets would have to be priced against this risk-less benchmark using the risk-adjusted stochastic discount factor (for a more detailed discussion, see section 3.2.1 and 3.2.2, respectively). In this context, it is important to notice that the price of the risk-less government, $Q_t = \frac{1}{1+i_t}$, and hence the nominal interest i_t is controlled by the central bank. However, the Euler equation implies that the representative household is always indifferent between the option 'consume today' and 'save in order to consume tomorrow'. As a consequence, aggregate savings are always zero. In other words, the financial market is characterized by a *no-trade equilibrium*, i.e. $B_t = 0$.

3.2. Pricing Kernel and Risk Premia

In the previous section it has been shown that monetary policy affects output and inflation in the baseline NK model only via its influence on the evolution of the short-term nominal interest rate. As Woodford (2003, p. 31) demonstrates, this even holds for the "cashless-limit" – a hypothetical reference point where no monetary frictions whatsoever exist – such that base money ceases to play any role in determining the policy rate. With perfect financial markets, money is not needed as a medium of exchange, which makes it theoretically implausible to model liquidity premia in the baseline NK model. Conventional interest rate policy in the baseline NK model is thus based on the Pure Expectations Hypothesis of the term structure (PEH). The PEH relies on the proposition that only expectations about future short-term rates – irrespective of any risk premia – affect the current level of long-term rates. Initial contributions to this theory trace back to the work of Irving Fisher, who wrote already in 1896 that

> "[...] interest realized on a very long bond, say 50 years is often lower [!] than on a 25 years' bond. This is explainable by the prevailing opinion that interest tends to fall, so that if the 50 years' investment were in two successive bonds of 25 years each, the interest realized in the second would be lower than in the first. The "actuarial average" of the two is equal to the interest realized in the 50 years' bond." (Fisher, 1896, p. 29)[8]

Fisher's ideas on the expectation hypothesis were taken up by Keynes (1930) and Hicks (1946), although both saw the reasons for the existence of term premium on longer-dated assets. Hicks explained the necessity of a positive term premium with a structural weakness on the demand side of the capital market, asserting that

> "[i]f no extra return is offered for long lending, most people (and institutions) would prefer to hold their money on deposit in some way or other. But this situation would leave large excess demand to borrow long which would not be met. Borrowers would thus tend to offer better terms in order to persuade lenders to switch over into the long market." (Hicks, 1946, p. 146)

However, those early analyses generally emanated from partial market models, whereas modern treatments of the expectations hypothesis rely critically on the concepts of general equilibrium and no-arbitrage. Hence, the next paragraph sheds light on the expectations hypothesis against the background of the popular consumption-based capital asset-pricing model (CCAPM).[9] Subsequently, the implications of the expectations hypothesis will be enlarged to a general equilibrium perspective in order to discuss its relevance for the portfolio balance effect.

3.2.1. Risk Premia in the CCAPM

Essentially all macro-finance models depart from the single fundamental asset pricing equation,

$$P_{i,t} = E_t\left[\mathcal{M}_{t+1} X_{i,t+1}\right], \qquad \langle 3.45\rangle$$

[8] Interestingly, this statement reveals that Fisher projected a secular decline in future interest rates which corresponds to an inverse term structure, a finding which is generally rejected by empirical studies of the term structure. In contrast, empirical studies generally identify an upward sloping yield curve (a normal term structure).

[9] The discussion of the CCAPM is mainly based on Cochrane (2001).

that equates the price of an asset i at time t with the expected product of the stochastic discount factor (SDF), $\mathcal{M}_{t+1}$, and the asset's expected payoff, $X_{i,t+1}$. With uncertainty about future asset payoffs and interest rates, the SDF maps future payoffs back to present. The concept of the SDF is closely related to the *law of one price* (LOOP): Two assets having identical payoff streams in every state s must trade at the same price. Otherwise, arbitrage opportunities would arise. Cochrane (2001, p. 64) thus shows that the LOOP necessarily implies the existence of a single SDF when agents value assets as perfect substitutes. Moreover, the existence of a positive SDF establishes a necessary and sufficient condition for markets to be arbitrage-free (Irle, 2003, p. 114). If there are $s = 1, \ldots, S$ discrete states of the world, complete markets imply that for each state a security exists that costs $p(s)$ today and pays one unit in state s and zero otherwise. Thus, if there are $i = 1, \ldots, N$ assets in the economy, the price of an asset i is given by

$$P(i) = \sum_{s=1}^{S} p_c(s) X(si). \quad \langle 3.46 \rangle$$

This can be rewritten by replacing the sum over state prices with the respective probabilities $\pi(s)$ of the states. Therefore, the state-density function is defined as

$$\mathcal{M}(s) = \frac{p_c(s)}{\pi(s)} \quad \langle 3.47 \rangle$$

which can be used in equation ⟨3.46⟩ to obtain

$$P(i) = \sum_{s=1}^{S} \pi(s) \mathcal{M}(s) X(s) = E[\mathcal{M}X]. \quad \langle 3.48 \rangle$$

This illustrates that a unique SDF exists only in case of complete financial markets. If markets are incomplete, multiple stochastic discount factors may exist (Campbell et al., 1997).

It is common to express equation ⟨3.46⟩ not in terms of asset prices but in terms of (gross) returns. For complete markets, this can be done by dividing equation ⟨3.46⟩ through $P(i)$ and defining $X(si)/P(i) = r(i)$ to be the gross return of asset i. This results in

$$1 = E\left[\mathcal{M}r(i)\right]. \tag{3.49}$$

The same approach is applied to price risk-free assets. An asset is called *risk-free* if it delivers a constant, state-independent payoff, i.e. $X(s) = \bar{X}$. Applying the above pricing equations to a risk-free asset gives the risk-free asset price as

$$\begin{aligned} P(f) &= \bar{X}\sum_{s=1}^{S} p_c(s) \\ &= \bar{X}\sum_{s=1}^{S} \pi(s)\mathcal{M}(s) \\ &= \bar{X}E\left[\mathcal{M}\right], \end{aligned} \tag{3.50}$$

implying that the no-arbitrage condition is fulfilled. If the risk-free asset is defined as a zero-coupon bond paying unity in each state of the world, i.e. with $\bar{X} = 1$, the above equation collapses to

$$P(f) = E[\mathcal{M}]. \tag{3.51}$$

This can be transformed to gross returns such that the SDF equals the inverse of the real risk-free interest rate (Cochrane, 2001, p. 13):

$$\begin{aligned} 1 &= \frac{E[\mathcal{M}]}{P(f)} = r^f E[\mathcal{M}] \\ &\Leftrightarrow \frac{1}{r^f} = E[\mathcal{M}]. \end{aligned} \tag{3.52}$$

The above deliberations can also be applied to macroeconomic DSGE models with utility-maximizing agents. As outlined in section 3.1.1, the household's optimization calculus in the baseline NK model implies that the nominal SDF has to equal the ratio of marginal utilities times the subjective discount factor β

$$E_t\left[\mathcal{M}_{t+1}\right] = \beta E_t \frac{U'(C_{t+1})}{U'(C_t)\pi_{t+1}}. \tag{3.53}$$

The basic idea of the nominal SDF in any DSGE model with a representative agent is that the equilibrium asset price has to be such that the agent is indifferent between sacrificing marginal consumption today and consuming the asset's payoff tomorrow. Hence, the price of any asset i must be

$$P_{i,t} = E_t \left[\beta \frac{U'(C_{t+1})}{U'(C_t)\pi_{t+1}} X_{i,t+1} \right]. \qquad \langle 3.54 \rangle$$

Since the gross return $r_{i,t+1}$ of any asset i equals the ratio $X_{i,t+1}/P_{i,t}$, dividing the above equation through $P_{i,t}$, yields[10]

$$1 = E_t \left[\beta \frac{U'(C_{t+1})}{U'(C_t)\pi_{t+1}} \frac{X_{i,t+1}}{P_{i,t}} \right] = E_t[\mathcal{M}_{t+1} r_{i,t+1}]. \qquad \langle 3.55 \rangle$$

Notice that for independent random variables X, Y, it holds that $E_t[XY] = E_t[X]E_t[Y] - cov_t(X,Y)$ with $cov_t(X,Y) = E_t(X - E_tX)(Y - E_tY)$, such that equation ⟨3.55⟩ can be rearranged to[11]

$$1 = E_t[\mathcal{M}_{t+1} r_{i,t+1}] = \underbrace{E_t[\mathcal{M}_{t+1}]E_t[r_{i,t+1}]}_{\text{risk-neutral component}} + \underbrace{cov_t(\mathcal{M}_{t+1}, r_{i,t+1})}_{\text{risk-adjustment}} \qquad \langle 3.56 \rangle$$

The first term on the right-hand side of equation ⟨3.56⟩ captures the mean return for an asset that investors would require if they were indifferent towards risk. The second term – the covariance between the SDF and the return of asset i – is the risk correction required by risk-averse investors. By establishing a link between asset returns and the consumption process, it explains why an asset whose return covaries positively with consumption must yield an expected excess return over the risk-neutral benchmark. Remember from equation ⟨3.53⟩ that the nominal SDF is high when the marginal utility of consumption in period $t+1$ is high. However, this corresponds to a low level of consumption in $t+1$ and high consumption in t. The economic intuition is as follows: risk-averse investors dislike volatility in consumption. To be willing to buy an asset that delivers low payoffs in states of the world where the level of consumption is already low, potential investors demand a risk premium, or, which amounts to the same

[10] This valuation formula for uncertain payoff streams in discrete time goes back to Rubinstein (1976).
[11] Cf. Wooldridge (2006)

thing, are only willing to buy this asset at a discounted price. Conversely, an asset that covaries negatively with consumption (i.e. positively with marginal utility) serves like an insurance contract. It delivers a positive payoff exactly in those states of the world where the level of consumption is low (the bad state). An asset with such payoff streams contributes positively to consumption smoothing and will thus be demanded even if its *expected* payoff is negative (the classic insurance example).

A risk-free security, on the other hand, delivers certain payoffs in each state of the world. Its covariance with the pricing kernel equals zero ($cov_t(\mathcal{M}_{t+1}, r_{t+1}) = 0$) and equation ⟨3.56⟩ simplifies to

$$r_t^f = \frac{1}{E_t\left[\mathcal{M}_{t+1}\right]}. \qquad \langle 3.57\rangle$$

Plugging this expression for the risk-free rate into equation ⟨3.56⟩ yields the expected excess return (the risk premium) of any risky asset i as

$$\begin{aligned} E_t[r_{i,t+1}] &= r_t^f(1 - cov_t(\mathcal{M}_{t+1}, r_{i,t+1})) \\ \Leftrightarrow E_t[r_{i,t+1} - r_t^f] &= -r_t^f cov_t(\mathcal{M}_{t+1}, r_{t+1}). \end{aligned} \qquad \langle 3.58\rangle$$

This equation indicates that the risk premium is inversely proportional to the covariance of its state-contingent return and the stochastic discount factor. It implies that an asset that has a high return in good times when aggregate consumption is high, but fails to pay out in bad times when aggregate consumption is low, has a negative return pattern in the eyes of the representative investor. In order for the investor to be willing to hold such an asset, it must pay an expected return in excess of the risk-free rate, i.e. it must offer a positive risk premium.

The quintessence of the CCAPM can be confirmed by the stylized facts of asset prices and the business cycle. Stock and Watson (1999, 2003), for instance, find pro-cyclical effects on macroeconomic dynamics and asset prices. As both asset returns and consumption tend to be low during recessions, investors do require relatively higher risk premia in recessions than in booms. Cochrane and Piazzesi (2005) also show that risk premia are higher in recessions than in boom phases, and they explain this pattern by a higher level of macroeconomic uncertainty during recessions periods. All in all, the empirical evidence suggests that risk premia vary counter-cyclically with the business cycle.[12]

[12]See Pesando (1975); Fama (1984); Tzavalis and Wickens (1997); Campbell and Cochrane (1999).

However, the high variation in risk premia that can be observed in the data are difficult to reconcile with the standard CCAPM. Especially the recent financial crisis has (re-)raised the question on *why* risk premia vary over time – and understanding this variation has been nominated to be "the central organizing question of current asset-pricing research" (Cochrane, 2011). In this context, the role of financial frictions and asset market segmentation seems to provide an interesting avenue of future research. In fact, the existing models in this field offer a much better fit to risk premia dynamics than the standard asset pricing model, where risk premia are solely a function of the representative agent's fluctuation in aggregate consumption.[13] In the following, I will briefly present the role of risk premia in the New Keynesian model before I turn to the more general caveats of incorporating risk premia into standard DSGE models.

3.2.2. Pitfalls of the NK Model

To quote Sargent (2010), "the New Keynesian IS curve is nothing more than an asset pricing equation." Therefore, consumption-based asset pricing theories should be able to explain the risk pricing and the main transmission channels of conventional monetary policy in the baseline NK model.

Interestingly, however, there are no risky assets in the baseline NK model. The sole asset with which households can transfer wealth over time is a one period government bond, which carries neither *default risk* nor *liquidity risk*.[14] Moreover, since the policy rate is assumed to be the same as the government bond rate, government bonds carry no *interest rate risk* either. Consequently, neither do term premia nor any other form of risk premia appear in the baseline NK model. Evidently, this represents an oversimplifying conjecture. By extending the model to include (default-free) long-term government bonds subject to interest rate risk, at least a positive term premium between short- and long-term government bonds should arise: If the future path of short-term interest rates is uncertain, interest rate risk emerges as rising discount rates cause a capital loss to investors whenever their desired investment period diverges from the maturity profile of the bond. By virtue of the Taylor-rule ⟨8.75⟩, short-term rates are indeed uncertain in the NK model, as they inherit the stochastic shocks to output, inflation, and monetary policy. Therefore, unless utility is linear in consumption, i.e. when $E_t \frac{U'(C_{t+1})}{U'(C_t)\pi_{t+1}} = 1$,

[13] See He and Krishnamurthy (2013); Adrian et al. (2014); Brunnermeier and Sannikov (2014a); Muir (2016).

[14] At least for an industrialized country with a highly liquid sovereign bond market and an independent central bank (acting as lender of last resort in sovereign bond markets), discarding default and liquidity risk is a generally accepted conjecture.

leading the covariance term to vanish in equation ⟨3.58⟩, interest rate risk provokes risk-averse households to demand a positive term premium that increases with the maturity of the bond.[15]

In general, the representative household is assumed to be risk-averse ($\sigma > 0$) leading to a convex utility function and to $E_t \frac{U'(C_{t+1})}{U'(C_t)\pi_{t+1}} \neq 1$. As a consequence, if long-term bonds are included in the baseline NK model, one should expect the yield on the risky long-term bond to carry a positive term premium over the risk-less short-term bond (section 8.1 presents an example of a baseline NK model including long-term bonds). However, this is not the case. Long-term rates carry no term premium and the pure expectations theory of the term structure still holds (cf. equation ⟨8.17⟩). Note that this stands in stark contrast to the implications of the no-arbitrage asset pricing equation presented above (equation ⟨3.58⟩). The fact that no term premium appears in the conventional reduced form equations of any basic microfounded DSGE model rests on purely mathematical grounds. It is the result of the standard procedure of log-linearizing the structural model around the steady state. The linearization process eliminates the term premium entirely, because the stochastic discount factor is identical to the risk-free rate up to a first order approximation, which is a manifestation of the certainty equivalence property of linearized models (Rudebusch et al., 2007).

To remedy this shortcomings and to allow for a more meaningful role of risk, Hördahl et al. (2007) use a more complicated second-order perturbation method. This rather complex approach, however, is only slightly more successful, because it yields only a constant term premium. Besides increasing in maturity, the term premium shows no reaction to other macro-variables of the model. The reason is that second-order approximations involve only the squared prediction error terms with constant expectations (a weighted sum of the respective shock variances). This is unsatisfying, as general equilibrium models that derive the term structure from the behaviour of optimizing agents should principally explain interest rate dynamics by the volatility of a wide range of macroeconomic variables.

Thus, modeling time-varying term premia in microfounded DSGE-models requires complex third-order approximation methods as done in the analysis of Rudebusch and Swanson (2008) and Ravenna and Seppälä (2006), for instance. However, these models' term premia show only a very weak empirical fit. Rudebusch and Swanson (2008) try to improve the fit by extending a standard DSGE model to incorporate large and persis-

[15]Note that this kind of interest rate risk is not present for the short-term government bond only because its yield happens to equal the policy rate.

tent external habits, a strategy proposed by Campbell and Cochrane (1999) to explain the equity premium puzzle in a consumption-based asset pricing model. In addition, Rudebusch and Swanson (2008) add various forms of labor market frictions (labor adjustment costs, real wage rigidities, staggered nominal wage setting), but even though none of this helps to significantly improve the fit of the term premium, it causes a trade-off: For the term premium to be in line with the data, these studies have to assume either implausibly high labor market frictions, or a very strong degree of risk aversion. Both, however, come at the cost of distorting the fit of the implied macroeconomic moments. Hence, Hördahl (2009) and Ravenna and Seppälä (2006) pursue another strategy: They try to increase the model fit by increasing the size and persistence of shocks. But of course, increasing the shock volatility also increases the volatility of output and other macroeconomic variables. Thereby, these studies exhibit a similar trade-off as in Rudebusch and Swanson (2008).

In conclusion, the failure of conventional DSGE-models – most notably of the standard workhorse New Keynesian Model – to simultaneously replicate the stylized facts of asset prices and macroeconomic variables may suggest the necessity of a modification of the underlying utility framework.

3.2.3. Alternative Utility Specifications: Epstein-Zin Preferences

As already noted by Lucas (1978, p. 1441), a drawback of the standard power utility function is that it jointly determines the coefficient of relative risk aversion together with the intertemporal elasticity of substitution (both are just reciprocals of one another). This, however, seems overly restrictive since it mingles two rather distinct economic concepts (Lengwiler, 2004, p. 202): Risk aversion mirrors an agent's sensitivity towards risk by measuring the willingness to substitute consumption across *states*. Intertemporal elasticity on the other hand measures the willingness to substitute consumption across *time*.

Epstein and Zin (1989) thus tried to disentangle these two aspects of preferences within the more general class of recursive utility functions, but without sacrificing too many features of the standard time-separable power utility framework.[16] Most importantly, Epstein-Zin preferences avoid the drawback of the standard time-separable power utility model that agents are indifferent to the temporal distribution of risk (Piaz-

[16]To be precise, Epstein and Zin (1989) and Weil (1989) build on the original contribution by Kreps and Porteus (1978), who provided the original theoretical framework for this kind of preferences.

zesi and Schneider, 2007b). This idea can be clarified by the following example: consider three hypothetical consumption plans – A, B and C – where consumption over an interval $[0; T]$ is contingent on a fair coin toss. In every program, the level of consumption is high (low), if the toss is heads (tail). However, the consumption stream of plan A is determined by a *once and for all* coin toss in period $t = 1$. Thus, scenario A delivers a highly persistent consumption path. In contrast, consumption payoffs under B are generated by periodically *repeated* tosses whereas the results are known at time $t = 1$ already. Finally, the consumption plan C is similar to B except for the fact that the t-th coin toss is not revealed before time t.

Intuitively, if an agent dislikes the high shock persistence, B should dominate A, since in the latter consumption is high if and only if it is high from the beginning (and low otherwise). In contrast, due to the serially independent tosses, consumption is more diversified under scenario B. Thus, a risk averse agent would choose consumption plan B. Note, however, although the resolution of uncertainty differs between scenarios B and C, this does not matter under time-separable utility. In other words, any agent characterized by a standard time-separable power utility function would be indifferent between the consumption path generated by option B and C. However, this result is invalid if we impose recursive Epstein-Zin preferences. Given that the parameter governing risk aversion is higher than the intertemporal elasticity of substitution, agents strictly prefer option B over C and A (Duffie and Epstein, 1992). This represents the fundamental difference to the power utility framework. It implies that if an agent's degree of risk aversion is higher than its subjective time preference, the agent prefers an early resolution of uncertainty about future consumption.[17]

Moreover, with respect to asset pricing, Epstein-Zin preferences allow to nest the predictions of the intertemporal consumption-based CAPM with the static CAPM (Duffie and Epstein, 1991). According to the first, it is the asset payoff's covariance with consumption growth that matters for asset specific risk premia whereas in the static CAPM it is the covariance of the asset return with the market portfolio that determines its riskiness. The key point with Epstein-Zin preferences is now that both components matter for an asset's excess return (Epstein and Zin, 1991). As shown in Campbell et al. (1997), for a log-normal representation this also offers the convenient property that a high risk aversion coefficient does not necessarily imply a low risk-free rate, since the elasticity

[17] In case risk aversion is lower than intertemporal elasticity of substitution, agents prefer high consumption persistence, i.e. they prefer option A over B.

of intertemporal substitution (which governs the risk-free rate) may well diverge from the value of the risk coefficient.

Finally, by disentangling the coefficient for risk aversion from the intertemporal elasticity of substitution, risk aversion can be amplified while all other model parameters remain constant. This should enable a positive term premium along the yield curve. Thus, Rudebusch and Swanson (2012) incorporate Epstein-Zin preferences into an otherwise standard DSGE model and they succeed in improving the fit of the model-implied term premium even without considerably compromising the fit to macroeconomic data (a problem they encountered in an earlier study where they adopted long-lasting external habits (Rudebusch and Swanson, 2008)). Unfortunately, however, the technical flaw of basic microfounded DSGE models whereupon time-variant term premia can be accounted for only up to a third-order approximation cannot be resolved when Epstein-Zin preferences are used.

3.3. Wallace Neutrality

The *Wallace neutrality* is an economic proposition going back to a seminal article by Neil Wallace (1981). With this article, Wallace provided the theoretical argument proving that QE is ineffective under certain market conditions. In Wallace's model, when the central bank issues reserves to purchase an asset, this affects neither the asset's price, nor its yield, nor does it have any effect on output and inflation. More importantly, this even holds for conventional open-market operations at positive levels of the short-term policy rate. Actually, at first sight this might seem like a counterintuitive result; but while the mathematics of the Wallace model are quite complicated, its economic intuition is rather simple.[18]

Key Aspects of Wallace's Model The model assumes an endowment economy where representative agents with perfect foresight live for two periods. In order to smooth consumption, young generations want to save parts of the single consumption good C. In order to do so, they can either invest in a storage technology with the return x, or they can buy (or sell) state-contingent contracts that deliver C in a particular state next period. However, these state-contingent contracts are ultimately backed only by the storage of C, i.e. the no-arbitrage condition requires that both options face the same expected return.

[18] Sargent (1987, pp. 305-324) offers a very useful representation of the Wallace model.

Now, when the central bank conducts open-market operations, it prints money to purchase parts of the single consumption good, which it then stores at the same rate as the private sector. After one period, this transaction will be reversed. That is, the central bank returns the consumption good plus the one period return in exchange for the previously issued money. In the no-arbitrage equilibrium, this necessarily implies that the return from storing via the central bank has to equal the return from the private storage technology. Now, a crucial result is that, if the central bank increases its amount of storage by engaging in an open-market operation, private storing falls by exactly the same amount. Thereby, the reduced private storage exactly offsets the effects of the central bank's trade.

Note also that 'money' in the Wallace model is similar to one-period zero-coupon bonds. In other words, there is no transaction motive for positive money holdings. As a result of the aforementioned aspects, it is clear that open-market operations have to be ineffective in Wallace's model: they do not lead to changes in inflation, nor do they change people's intertemporal consumption profile.

Recently, the insight of Wallace's irrelevance proposition has been famously reiterated by Woodford (2012), who stressed that in modern representative household theory, "the market price of any asset should be determined by the present value of the random returns to which it is a claim, where the present value is calculated using an asset pricing kernel (stochastic discount factor) derived from the representative household's marginal utility of income in different states of the world (Woodford, 2012, p. 61)." While a similar point has been discussed in section 3.2.1, Woodford continues by noting that "insofar as a mere re-shuffling of assets between the central bank and private sector should not change the real quantity of resources available for consumption in each state of the world, the representative household's marginal utility of income in different states of the world should not change. Hence the pricing kernel should not change, and the market price of one unit of a given asset should not change, either, assuming that the risky returns to which the asset represents a claim have not changed (Woodford, 2012, p. 62)."

Interestingly, this statement implies that even central bank purchases of *risky* assets have no impact in those class of models. The reason is that if households swap risky bonds for essentially risk-less central bank reserves, total risk has only seemingly vanished from the private sector's balance sheet. In case the risk materializes as risky bonds default when they sit on the central bank's balance sheet, any resulting losses will imply lower (or even negative) remittances to the Treasury. This, in turn, will result in higher taxes (or lower government spending) in the future. Thus, from a general equilibrium perspective, the household's after tax income will be just as dependent on the risky bonds' payoffs as before the central bank's open-market operation (for a formal representation of this point in the context of a representative household model, see Eggertsson and Woodford, 2003).[19]

Against this background, it can be concluded that for the Wallace neutrality to hold, only two assumptions must be fulfilled. Firstly, assets must be valued only for their *pecuniary* returns, i.e. all non-pecuniary factors that could explain why certain assets are demanded (like transaction services) are disregarded. Secondly, investors must be able to purchase arbitrary quantities of assets at identical market prices, without credit constraints other than their overall budget constraint (Cúrdia and Woodford, 2011).

Based on these assumptions, the following three 'dogmas' emerged as the pre-crisis consensus of monetary policy making: first, open market operations in government bond markets (or any other asset market) do not affect relative prices (a corollary of this view is that public debt management can be separated from monetary policy). Second, the short-term policy rate is the only relevant monetary policy tool. In particular, the influence of balance sheet policies on credit or term premia is completely discarded. Third, the liquidity status of the commercial banking sector is seen as irrelevant. The idea is that as long as adequate capital standards are in place, any temporary liquidity need can be readily met on perfectly functioning interbank markets (Turner, 2014).

However, in the same manner as other irrelevance theorems of economic theory – as for instance the irrelevance of the capital structure for the value of a firm (*Modigliani-Miller Theorem*) or the irrelevance of government financing via taxes or deficits (*Barro-Ricardo Theorem*) – the Wallace neutrality represents a benchmark concept in frictionless monetary models with optimizing agents.[20] In this vein, it should serve as a theoretical starting point for discussions about why things might behave differently in the real world.

[19]In contrast to Eggertsson and Woodford (2003), Benigno and Nisticò (2017) take a general-equilibrium perspective to assess under which conditions risky open-market operations might be *non-neutral* because of the potential losses that they imply for the central bank's balance sheet. Their most intuitive result is that open-market operations will be non-neutral if the treasury is unable or unwilling to levy taxes in order to cover the losses made by the central bank. In that case, the materialization of risk does remain in the hands of the whole government (Treasury and/or central bank), which is concomitant to a wealth transfer to the private sector. Hence, this monetary/fisal policy regime – which essentially represents a form of *helicopter money* – ultimately leads to rising inflation.

[20]The respective sources for the two irrelevance theorems are Modigliani and Miller (1958) and Barro (1974), while the basic Ricardian concept is contained in Ricardo (1951, vol. 1, pp. 244-249). A critical review of the Barro-Ricardo Theorem is provided by Buchanan (1976).

Model Extensions The Wallace model is often criticized because it abstracts from a liquidity premium on money, implying that money and short-term government bonds are perfect substitutes – even for positive levels of the short-term interest rate. As mentioned above, the reason is that money only serves as a store of value, but plays no role facilitating transactions. From a monetary policy perspective, this implies that even conventional open-market operations have no effect in setting the short-term policy rate. Of course, this is a rather strong claim, since practical experience proved that monetary policy does implement the short-term policy rate with the use of open-market operations.

As a consequence, Wallace's irrelevance proposition is supposed to be of little practical relevance, at least for conventional monetary policy operations. To rectify this shortcoming, Eggertsson and Woodford (2003) introduce a liquidity premium on money by incorporating real money balances into the representative household's utility function. As a result, open-market operations in short-term government bonds are only effective as long as money holdings yield a positive liquidity premium (i.e. as long as the short-term interest rate is positive). When the demand of real money balances becomes satiated, however, additional money balances provide no further liquidity service and the short-term interest rate drops to zero. Since this coincides with the perfect substitutability of money and short-term bonds, further conventional open-market operations in short-term bonds become ineffective at the zero lower bound.[21]

It has to be noted that the irrelevance proposition at the zero lower bound does not only hold for central bank purchases of short-term bonds, but also purchases of long-term bonds – even if interest rates on long-term bonds are still positive. The reason is that Eggertsson and Woodford (2003) assume frictionless financial markets that give rise to perfectly integrated bond markets, while both short- and long-term bonds are only valued for their pecuniary returns. Thus, apart from the different degrees of interest rate risks, short-term bonds represent perfect substitutes for long-term bonds, implying that the yield curve is connected through the expectations hypothesis of the term structure.

Model Critique The heavy use of large-scale asset purchases since 2008 has sparked off an intense debate on the implications of Wallace's irrelevance theorem for practical monetary policy (see Cohen-Setton and Monnet, 2012 and the references therein). In this

[21]Once again, note the difference between the proposition of Eggertsson and Woodford (2003) and the original irrelevance proposition of Wallace (1981): Eggertsson and Woodford (2003) argue that open-market operations are irrelevant only at the zero lower bound, whereas Wallace (1981) claims that they are irrelevant irrespective of the level of the short-term rate.

context, a widespread critique against Wallace is based on his assumption of perfectly flexible financial markets and rational arbitrageurs not subject to any borrowing constraint. In particular, if binding constraints on participation in certain markets exist, this could invalidate the irrelevance result, because the neutralization of asset purchases à la Wallace might be distorted. To see this, consider the following scenario: suppose the central bank engages in quantitative easing by purchasing long-term government bonds. For those purchases to be neutralized, rational investors must realize the arbitrage opportunity and short-sell government bonds by the same amount. Yet if arbitrageurs are credit constraint – or if they refuse to short-sell the entire amount because that would imply a heavily undiversified portfolio – monetary policy will succeed in pushing bond prices above their fundamental value. In fact, given the unlimited funds of the central bank, even deep-pocket investors will at some point run against their budget constraint. Thus, if limits to arbitrage exist, the resulting market segmentation gives monetary policy the power to influence asset prices through the so-called *portfolio balance effect*.[22]

Another argument is that if unconventional monetary policies contribute to the stabilization of distressed banks, or, more generally, if they relax credit market frictions by expanding reserves (Cúrdia and Woodford, 2011), this also generates non-neutral results. Finally, in the Wallace model there is absolute certainty that QE by the central bank will be ultimately reversed. In the real world, however, agents cannot be hundred percent sure whether QE will be completely reversed in the future. In other words, there are numerous reasons that may invalidate the Wallace neutrality in the real world.

3.4. Concluding Remarks

In summary, the above observations cast a rather pessimistic light on the ability of structural DSGE models to simultaneously fit the term premium and macroeconomic variables. The fundamental theoretical reason is that agents can insure themselves against consumption fluctuations either by adjusting labor supply, or, if this self-insurance mechanism is vitiated through labor market frictions, by purchasing state-contingent securities on complete financial markets. Since both insurance strategies deliver a relatively flat intertemporal consumption profile, the role for the term premium remains negligible.

[22] The theoretical and empirical foundations of the portfolio balance effect will be analyzed in Part II of this thesis.

Consequently, standard DSGE models like the baseline NK model lack the conditions conducive for central bank asset purchases to have any effect on asset prices and yields – which entails that such operations do not even change inflation. Instead, most monetary DSGE models include a Taylor rule that abstracts from open-market operations but assumes that the central bank sets the interest rate outright. Ultimately, this prompts the conclusion that DSGE models call for financial frictions in order to simultaneously generate term premia, a good fit of macroeconomic variables, and a role for non-neutral (unconventional) open-market operations. A model that incorporates these features will be laid out in chapter 8.

Part II.

Financial Market Effects of Unconventional Monetary Policies

4. Unconventional Monetary Policy – How Does it Work?

4.1. Key Terms and Concepts

Since the recent economic and financial crisis *quantitative easing* has become the buzz word for various unconventional monetary policies involving the central bank balance sheet. Given the specific channels and effects of individual operations, this very broad definition disguises important aspects of the existing measures. A first step towards a reasonable characterization should distinguish between *forward guidance*, *quantitative easing*, and *qualitative easing*.

4.1.1. Forward Guidance

Theoretical Concept In normal times, monetary authorities provide enough information for private market participants to be able to anticipate near-term policy rates by explaining the various factors underlying a given policy decision. Nevertheless, central banks have occasionally used more direct signals about future policy rates already before the financial crisis. However, in those episodes, the use of forward guidance was mainly confined to mitigate the impact of an imminent policy decision on financial markets (European Central Bank, 2014a).[1] This approach changed with the onset of the financial crisis. Since then, forward guidance constitutes an additional monetary policy tool that is used to provide the necessary monetary stimulus in the face of a liquidity trap (see Fig. 4.1).

[1]For evidence on forward guidance prior to the financial crisis, see e.g. Gürkaynak et al. (2005).

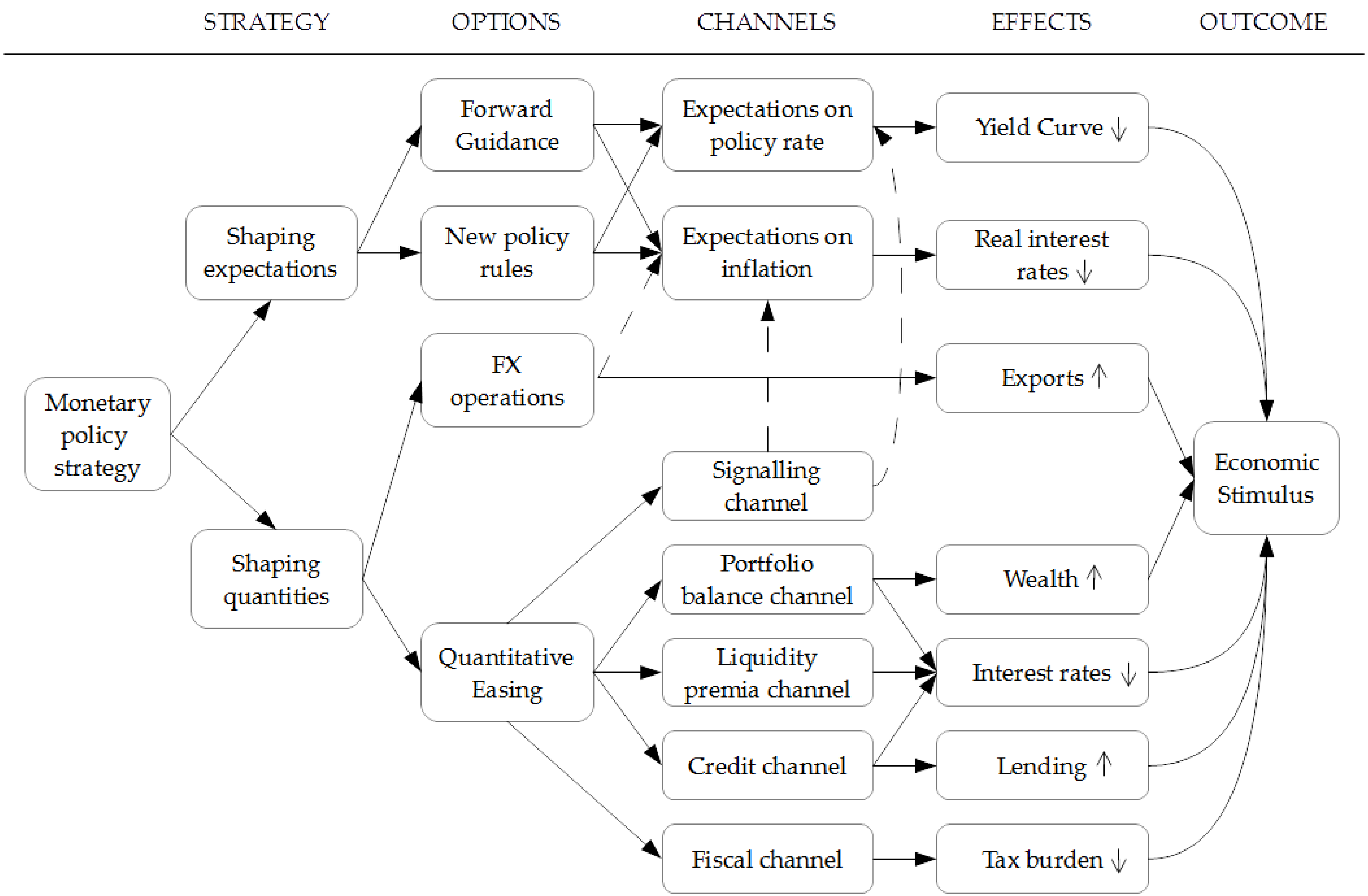

Figure 4.1.: Transmission channels of unconventional monetary policy

In this regard, the concept of forward guidance goes beyond the classical 'management of expectations', which has long been recognized as an important part of central bank communication (Svensson, 2004; Woodford, 2005a).[2]

Ideally, effective forward guidance lowers *future* policy rates and thereby also longer-term rates even if *current* policy rates are stuck at their zero lower bound.[3] Consequently, if the real rate falls below the households' time preference rate, the latter increase their current consumption at the expense of future consumption. Evidently, this is the standard result of an expansionary monetary policy shock in any DSGE model (see, for instance, Bhattarai et al., 2015).

Another reason why central banks might offer forward guidance is that they want to prevent excessive interest rate volatility from affecting their monetary policy stance in a way that hampers the transmission of an existing amount of accommodation. Therefore, most central banks combine their asset purchase programs with some form of forward guidance.

Forms of Forward Guidance Principally, forward guidance can be discerned along two dimensions. Firstly, it can be related to monetary policymakers' expectations about the economic outlook. Since this type of guidance relies on a forecast, it is referred to as *Delphic forward guidance*. A decisive feature of Delphic forward guidance is that it does not constitute a commitment on the part of the central bank. Instead, it only gives guidance on the expected path of future policy rates, conditional on the economic outlook.

Alternatively, if forward guidance contains a commitment to maintain low policy rates for longer than economic conditions would warrant, this is called *Odyssean forward guidance*. In this second form of forward guidance, the central bank 'ties its hands', i.e. commits to keep policy rates unchanged even when the inflation outlook rises (just like Odysseus tied himself to the pole to withstand the sirens).

Technically (and less mythical), practical forward guidance thus either relates to a given time period (*calendar-based*), or is conditional on certain economic conditions (*state-contingent*). Moreover, it might include specific numerical values (*quantitative*), or be ex-

[2]Clearly, with its emphasis on the expectations channel, forward guidance is closely related to the 'management of expectations' view. Adherents are also referred to as "expectationalists" in the literature (Morris and Shin, 2008).

[3]While Keynes envisioned the money market to be in a liquidity trap at some positive level of interest rates, in modern macroeconomics it refers to a situation in which the the short-term policy rate is zero (Krugman, 1998; Eggertsson and Woodford, 2003; Eggertsson, 2006).

pressed in vaguer terms (*qualitative*).[4] In the following, I will try to categorize the Fed's and the ECB's forward guidance along those dimensions.

The Fed's Forward Guidance Over time, the Fed's formulation of forward guidance has included all of the above dimensions. In December 2008, the FOMC began with *qualitative guidance* indicating that "the Committee anticipates that weak economic conditions are likely to warrant exceptionally low levels of the federal funds rate for some time" (Board of Governors of the Federal Reserve System, 2008). Then, in August 2011, the FOMC switched to *qualitative calendar-based* forward guidance by stating that it expected exceptionally low levels of the fed funds rate "at least through mid-2013" (Board of Governors of the Federal Reserve System, 2011).[5] After a series of minor modifications to this date-based guidance, the FOMC in December 2012 finally decided to provide *quantitative state-contingent* forward guidance conditional on the evolution of the employment and inflation rate. In particular, the Committee said that it would keep the fed funds rate at the current target range of 0-0.25 percent at least as long as the unemployment rate remained above 6.5 percent, subject to the condition that inflation between one and two years ahead was projected to be no more than half percentage point above the Committee's long-run goal of 2 percent, and long-run inflation expectations remained well anchored (Board of Governors of the Federal Reserve System, 2012).

A year later, when the US unemployment rate had almost decreased to the previously defined 6.5 percent threshold, the FOMC announced that it would consider additional information besides just current unemployment and inflation figures, i.e. indicators of inflation pressures and inflation expectations, as well as readings on financial developments. Based on these indicators, the FOMC then decided that the target range for the fed funds rate would remain at its current level "well past the time that the unemployment rate declines below 6.5 percent" (Board of Governors of the Federal Reserve System, 2013a).[6]

[4]This classification is based on Borio and Zabai (2016).

[5]This date was later changed to late 2014, and then to mid-2015. See also Mester (2014) for a discussion on the evolution of the Fed's forward guidance.

[6]Very interestingly, in a speech given in September 2016, the Fed's Chairwomen Janet Yellen mentioned hysteresis effects as an important factor that could explain why monetary policy should stay more accommodative during recoveries than would be called for by a standard Taylor rule (Yellen, 2016). With regard to the US experience, the study by Reifschneider et al. (2015) estimates that potential output by 2016 was 7 percent below what could have been expected based on its pre-crisis trajectory. Furthermore, the study suggests that much of this decline is attributable to factors that occurred as a result of the severe recession and sluggish recovery.

The ECB's Forward Guidance The Fed was of course not the only major central bank that adopted explicit forward guidance in the aftermath of the financial crisis. The European Central Bank, the Bank of England, the Bank of Japan, the Bank of Canada, the Bank of New Zealand, and the Swedish Riksbank have all used some form of forward guidance about the likely path of their future policy rates. And similar to the Fed, all of these central banks changed the formulation of their forward guidance over time.

For instance, the ECB introduced forward guidance in July 2013 against the backdrop of increased volatility in money markets, which caused an undesired tightening of its monetary policy stance and an effective withdrawal of previously introduced accommodative policy measures. Therefore, the Governing Council announced that it expected "the key ECB interest rates to remain at present or lower levels for an extended period of time" (European Central Bank, 2013). By relating the length of expansionary policy rates to the outlook for inflation and real economic activity, the ECB pursued an *open-ended* but *qualitative state-contingent* forward guidance.[7] In March 2014, the Governing Council then qualified this previous formulation somewhat, when it clarified that, despite an improvement in the outlook for inflation and economic activity, monetary policy rates would remain low as long as there was a "high degree of unutilised capacity" in the euro area economy (European Central Bank, 2014b).[8]

In contrast to the Fed, however, the ECB always abstained from giving an explicit end-date or numerical threshold in its forward guidance communication. That is, the ECB's forward guidance has always been a Delphic form of forward guidance. Even in March 2016, when the ECB expanded its monthly asset purchases from €60 to €80 billion, the Governing Council announced that it expected "the key ECB interest rates to remain at present or lower levels for an extended period of time, and well past the horizon of our net asset purchases" (ECB, 2016c). By the time of writing, the APP is "intended to run until the end of December 2017, or beyond, if necessary, and in any case until the Governing Council sees a sustained adjustment in the path of inflation consistent with its inflation aim" (European Central Bank, 2017). However, given that forward Eonia rates for the ECB meeting in December 2017 stood about 8 basis points above the Eonia spot rate of minus 0.35 percent in March 2017, money markets seem

[7] Noteworthy, the ECB began to implement forward guidance even before it exhausted the room for conventional interest rate cuts. This contrasts with the usual practice of using forward guidance as a supplement to further monetary easing at the zero lower bound.

[8] In fact, the high flexibility that comes with the term "unitilised capacity" provides some kind of escape clause that enables the ECB to keep its key policy rates at low levels despite an increase in inflation and economic activity. Similar to the Fed's experience, the rationale for this strategy can be traced back to potential hysteresis effects that may result from excessive slack in the economy.

to expect the deposit rate to have been slightly increased by December 2017 (Reuters, 2017).

Empirical Facts Ultimately, the effectiveness of forward guidance would have to be assessed against the adjustments which are made to the economy by changes in market prices. Due to a missing counterfactual, however, such an assessment is difficult to realize in practice. Therefore, most empirical studies focus on market reactions around announcement dates. In this context, Table 4.1 displays an overview of the empirical estimates of forward guidance in the US and the euro area.[9] Overall, these studies prove that forward guidance had a statistically significant but economically modest impact on the selected economic variables in both jurisdictions.

Time-Inconsistency Issues A drawback of forward guidance under inflation targeting is that the policy is subject to a time-inconsistency problem. The latter arises because effective forward guidance requires that the central bank allows the inflation rate to overshoot once the economy has recovered from the liquidity trap. This entails that the central bank must accept a *lower* future policy rate than a standard forward-looking Taylor rule based on the usual stabilization objectives would suggest. In other words: the central bank must "promise to be irresponsible" (Krugman, 1998, p. 139); unfortunately, rational households understand that a central bank with an inflation target lacks a motive *ex post* to be as expansionary as it wanted them to expect *ex ante* and therefore the stimulative effects from pure 'open mouth policies' are likely to be small.

Commitment Strategies One way to resolve the time-inconsistency problem is that instead of a *purely forward-looking* inflation target, monetary policy pursues a *price level target* (Eggertsson and Woodford, 2003; Woodford, 2012). The crucial difference between both strategies is that in response to a price level shock, a central bank with an inflation target stabilizes the inflation rate, but accepts a drift in the price level. By contrast, under price level targeting, the central bank corrects the effects of the shock on the target path of the price level (cf. Figure 4.2). In case of an adverse price shock, however, this means that the inflation rate must temporarily overshoot the envisioned trend inflation (and vice versa for a positive price shock). Thereby, monetary policy becomes *history-dependent* (Bundesbank, 2010). In terms of credible forward guidance, this might contribute to the successful implementation of a lower future policy rate, because it ma-

[9] For empirical evidence on Sweden, see inter alia Rosenberg (2007); for New Zealand McDermott (2016); for the UK Hofmann and Filardo (2014); and for Japan Shirai (2013).

Study	Method	Form of FG	Key results
U.S.			
Campbell et al. (2012)	Time series regressions on asset prices	Open-ended and calendar-based	Large influence on 2- and 5-year Treasury yields; strongest impact on 10-year yield
Woodford (2012)	OIS rates around announcements	Calender-based	Flattening of OIS rates after "mid-2013" and "mid-2014" announcements
Raskin (2013)	Time series regression on option implied interest rate distributions	Calender-based	Percentiles out to 3-years became unresponsive after "mid-2013" announcement
Swanson and Williams (2014)	Evidence from survey of forecasters; time-series regression on Treasury and Eurodollar future yields	Open-ended and calendar-based	FG affected beliefs about ZLB length
Hofmann and Filardo (2014)	Event study and evidence from futures-implied volatility of interest rates	Open-ended, calendar-based, quantitative state-contingent	Futures rates and long-term yields declined on most announcements, volatility of interest rate futures fell at short horizons
Giannone et al. (2015)	Panel regression on private interest rate forecasts	Calender-based	FG announcements lower short-term rates 4 quarters ahead by 15 bp, long-term rates by 20 bp, raising 1 year GDP and inflation expectations by 0.3 percentage points
Swanson (2015)	Time series regression	Open-ended, calendar-based, quantitative state-contingent	FG decreases Treasury yields as far out as 10 years; boom in stock market and depreciation of the dollar
EA			
European Central Bank (2014a)	Event study on forward interest rates and option-implied interest rate distributions	Open-ended, state-contingent	FG in July 2013 decreased forward rates by 5 basis points at maturities over six months. Dispersion of short rate expectations declined with the introduction of FG
Hofmann and Filardo (2014)	Event study and evidence from futures-implied volatility of interest rates	Open-ended, state-contingent	FG in July 2013 decreased futures rates at the one- and two-year horizon by 7 and 8 basis points, respectively
Picault (2017)	Event study and time series regression on EONIA OIS swaps	Open-ended, state-contingent	FG lowered OIS rates for maturities within 10 months and 3 years

Table 4.1.: Impact of Forward Guidance on Selected Variables

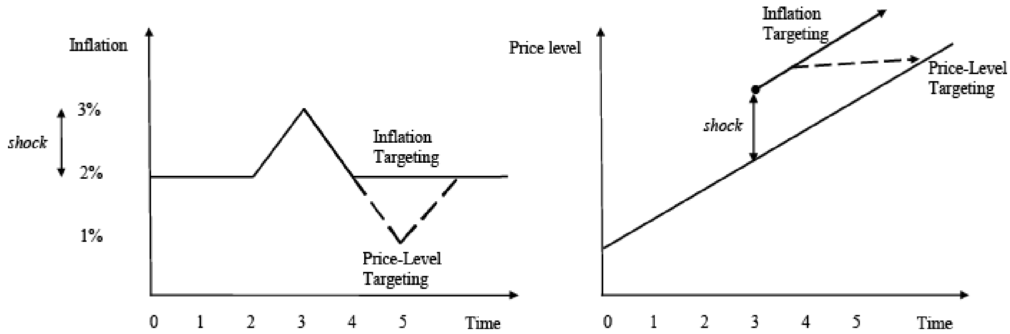

Figure 4.2.: Inflation and price level targeting in response to a price shock

kes the necessary overshooting of the future inflation rate consistent with the monetary policy rule.

An alternative approach to resolve the time-inconsistency issue of forward guidance is to accompany the announcement of a lower future policy rate with an increase in duration risk on the central bank balance sheet (see also section 5.2.1). The latter can be achieved either through outright purchases of longer-term securities (quantitative easing), or through swapping short-term against long-term securities on the central bank's balance sheet (qualitative easing). Both measures could thus enhance the credibility of the signal to keep policy rates lower for longer, since reneging on this promise would cause a loss for the central bank (Clouse et al., 2003).[10]

Drawbacks and Criticism Even if the time-inconsistency problem could be resolved, practical forward guidance might face other challenges: a widespread criticism is based on the assumption of frictionless financial markets and the permanent income hypothesis. A somewhat related criticism casts doubt on whether the heavy dependence on the expectations channel, i.e. promises that far future interest rates will have substantial effects on current economic conditions, do actually work in practice. Ultimately, forward guidance will stimulate economic activity only if it changes private sector beliefs about the central bank's reaction function. If, however, private market participants think the central bank has superior information about the true state of the economy, then a more expansionary policy stance could even have adverse effects, because it can lead to a significant deterioration in the economic outlook.[11]

[10] A valid objection to this strategy is that it is not immediately obvious why a central bank with the power to print money should be overly concerned about balance sheet losses (Bernanke and Reinhart, 2004).

[11] For forward guidance to have such unintended consequences, one has to assume rather strong information asymmetries between the private sector and the central bank. Therefore, Woodford (2005a, 2012) holds a rather sceptical view on whether such adverse effects occur in practice.

Thus, especially during crisis times – when uncertainty and credit constraints are typically on the rise – those conjectures may result in an overly optimistic view on the stimulative effects of forward guidance (McKay et al., 2016).

4.1.2. Quantitative vs. Qualitative Easing

While forward guidance rests primarily on *shaping expectations*, both quantitative and qualitative easing also involve the manipulation of *asset quantities* available to private agents (see Fig. 4.1). Since every quantitative operation is accounted for on the central bank's balance sheet, the textbook view (Bernanke and Reinhart, 2004; Goodfriend, 2011) differentiates *quantitative* from *qualitative* easing by the respective effect on the central bank's balance sheet (see Fig. 4.3).

Quantitative Easing *Pure quantitative easing* focuses on the quantity of bank reserves, i.e. on the liability side of the central bank balance sheet. Therefore, the composition of loans and securities on the asset side of the central bank's balance sheet is only incidental (Bernanke, 2009). Pure QE is thus characterized by an expansion of the monetary base which, as a byproduct, leads to an increase in the *conventional* asset holdings on the central bank balance sheet (see Fig. 4.3 left panel).[12] The expansion in the monetary base is mainly driven by commercial banks' accumulation of excess reserves, since the supply of banknotes is always endogenously determined by the currency demand of the private sector. From a monetarist perspective, large excess reserves in the banking system should trigger an increase in overall bank lending, in nominal income, and broader monetary aggregates. However, such a money multiplier view on the transmission mechanism of quantitative easing seems unconvincing, since broader monetary aggregates like M3 have largely decoupled from the massive base money expansion since 2008. Instead, it seems more convincing that quantitative easing has acted through stabilizing crisis-elevated spreads in distressed financial markets, rather than through the envisioned quantity effects in terms of the money supply (Lenza et al., 2010).

Qualitative Easing *Pure qualitative easing* on the other hand focuses on the asset *composition* but leaves the size of the balance sheet untouched (see Fig. 4.3 right panel). Since the composition of loans and securities on the asset side of the central bank's balance sheet is the crucial feature of qualitative easing, it is sometimes also called credit

[12] In this context, "conventional assets" denote the typical assets held by the central bank in normal times.

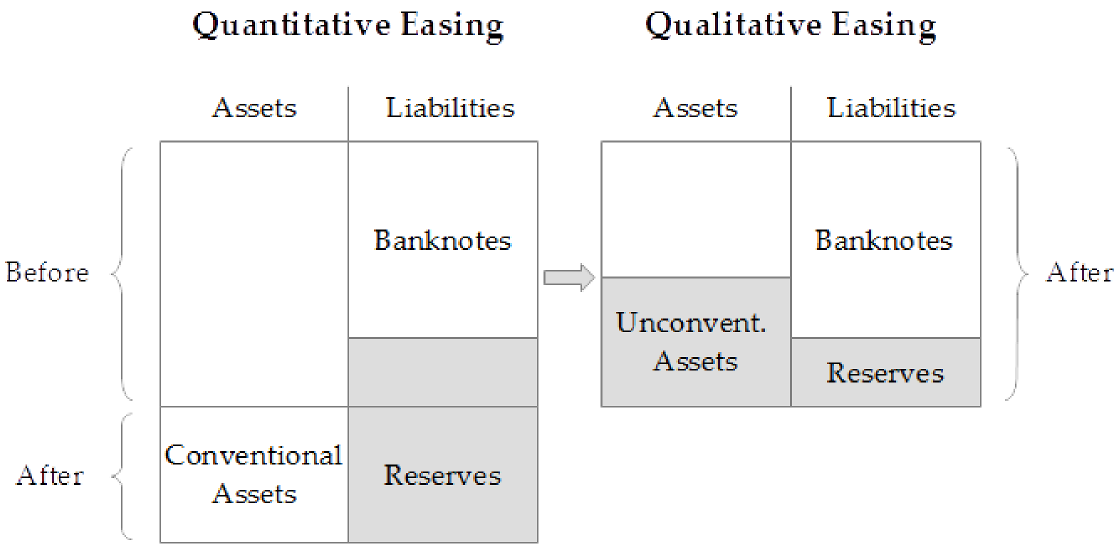

Figure 4.3.: Textbook view on quantitative vs. qualitative Easing ⋄ *Source:* Own illustration based on Lenza et al. (2010)

policy in the literature. A typical operation involves a swap of low-risk short-term governments bonds (conventional assets) against risky private securities (unconventional assets). The main goal is to reduce risk premia in private asset markets. Therefore, official credit policies are especially effective if private credit markets are severely impaired (and risk spreads elevated). A more detailed analysis of the financial market and macroeconomic effects of both quantitative and qualitative easing is given in chapters 5, 8 and 9, respectively.

4.1.3. Taxonomy of Recent Monetary Policy Measures

Examples of Qualitative Easing A recent example for pure qualitative easing is the Fed's *Term Auction Facility* (TAF) of December 2007. Although the effects on total liquidity were sterilized (i.e. the Fed's balance sheet size remained constant, cf. left Panel of Figure 4.4), TAF enabled the Fed to provide term funding to a broader range of counterparties and against a broader range of collateral than what it accepted in its open market operations (Board of Governors of the Federal Reserve System, 2010). From a qualitative perspective, this is fairly similar to the Fed's *Maturity Extension Program* (MEP) of 2011. During this program, the Fed swapped short-term government bonds for long-term government bonds. Overall, the MEP had a size of $400 billion and was intended to reduce longer-term yields.

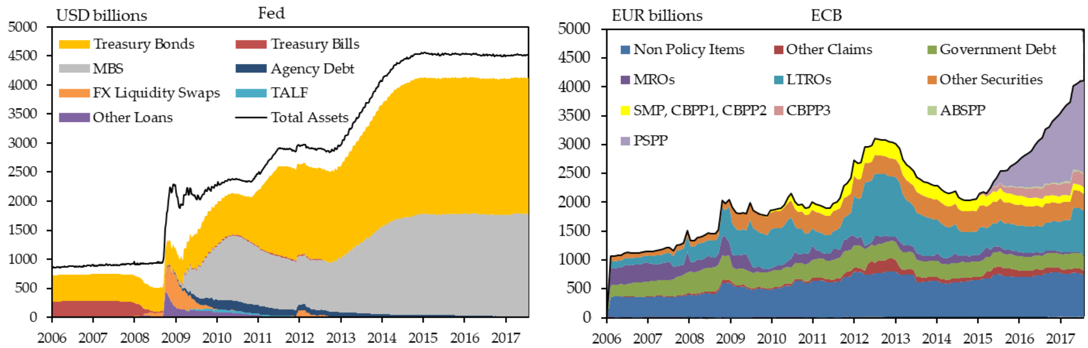

Figure 4.4.: Central bank asset positions (Fed vs. ECB) ⋄ *Source:* Fed, ECB, Bloomberg

Another example of qualitative easing is the ECB's *Securities Market Program* (SMP). With this program, the ECB purchased euro area government bonds for a total amount of €218 billion, but sterilized the resulting liquidity impact with specific fine-tuning operations. Since the purchases under the SMP were skewed towards the bonds of distressed euro area countries – about 50% of the SMP holdings are Italian bonds, followed by Spanish and Greek bonds (20% resp. 16%) – the SMP constituted a form of credit easing for those countries.

Examples of Quantitative Easing As the financial crisis intensified after the bankruptcy of Lehman Brothers, the Fed decided to support credit markets more broadly and initiated its first large-scale asset purchase (LSAP) program in November 2008. By the end of the program, the Fed had purchased assets worth of $1.75 trillion, whereof housing GSE debt and MBS accounted for more than 80 percent.[13] The intention was to "reduce the cost and increase the availability of credit for the purchase of houses, which in turn should support housing markets and foster improved conditions in financial markets more generally" (FOMC, 2008). Since the liquidity impact of the program was not sterilized, it roughly doubled the size of the Fed's balance sheet – which is why it is commonly referred to as *QE1* in the literature. This notion is misleading, however, since the program's priority to housing assets differentiates it from pure quantitative easing as defined above. Instead of pure quantitative easing – which the Bank of Japan pursued from 2001 to 2006 by setting a target for current account balances on its liability

[13] The Fed enlarged its first LSAP program in March 2009. The purchases ended in March 2010.

side (Shiratsuka, 2010) – QE1 mingled features of qualitative easing (the composition effect) with quantitative easing (the size effect).[14]

With respect to the euro area, the ECB's *Public Sector Purchase Program* (PSPP) which started in 2015 represents the clearest case of quantitative easing, although some of the ECB's earlier measures have already embodied similar features. For instance, a main element of the ECB's *enhanced credit support* was to switch its regular refinancing operations from variable rate tenders with fixed allotment to fixed rate tenders with full allotment (FRFA). As this resulted in an immediate expansion of excess reserves, this policy had a similar effect as pure quantitative easing. In this sense, the two 3-year LTROs of 2011 and 2012, which resulted in a net liquidity increase of about €520 billion as well as a significant increase in the ECB's maturity structure, also resembled some form of quantitative easing.

In summary it can be ascertained that during the pre-Lehman turmoil, unconventional operations represented variations on qualitative easing which were mainly geared towards the liquidity conditions of financial intermediaries.[15] This changed in the post-Lehman period. In the face of dramatically deteriorating economic conditions and with no further scope for cuts in policy rates, central banks around the globe initiated unprecedented expansions of their balance sheets (see Figure 4.5). The latter involved both qualitative and quantitative easing in order to boost the effectiveness in a situation of extreme market stress. Hence, Shiratsuka (2010, p. 83) concedes that the term QE should be understood as a package of policy measures that make use of both the asset and the liability side of the central bank's balance sheet (broadly defined quantitative easing).

4.1.4. Negative Policy Rates

Negative policy rates are the most recent addition to the unconventional monetary policy measures. Starting in mid-2014, the ECB, the Swiss National Bank (SNB), Danmarks Nationalbank (DN) and the Swedish Riksbank have introduced negative policy rates either by lowering the target for the overnight rate to below zero (SNB, Riksbank) or by charging negative rates for the deposits at the central bank (SNB, DB, Riksbank, ECB).[16] Moving the marginal policy rate into negative territory can serve multiple goals. It can

[14] In fact, Bernanke stressed that the Fed's LSAPs should be best understood as a form of credit easing (Bernanke, 2009).

[15] Bini Smaghi (2009) calls the ECB's FRFA policy "endogenous credit easing" because the liquidity supply was passively accommodated to financial intermediaries demand with the explicit aim to revive an impaired European interbank market.

[16] In February 2016, the Bank of Japan also lowered the rate on its deposit facility to minus 10 basis points.

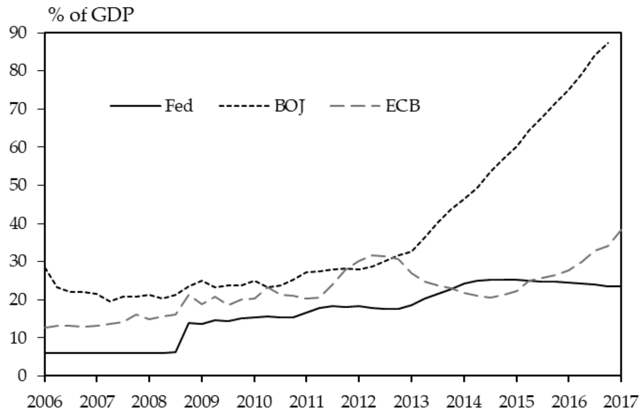

Figure 4.5.: Central bank balance sheets as percentage of GDP ⋄ Measured using quarterly data for nominal GDP ⋄ *Source:* Fed Fred, ECB, BOJ, Bloomberg

help accommodative monetary policy to reduce the real rate to levels consistent with stable inflation and full employment, or offset appreciation pressures on the exchange rate. In fact, the motivation for negative policy rates differed across the jurisdictions in which they were implemented. While the SNB and the DB used negative rates primarily to defend their exchange rates, the ECB, the Riksbank and the BoJ implemented negative marginal rates mainly to achieve their inflation targets.

In principle, central banks can set interest rates on reserves at any arbitrary level, because there is nothing the banking system can do to avoid holding them (Borio, 1997a; Borio and Disyatat, 2010). Consequently, central banks can even set negative rates for reserves. As commercial banks seek to avoid the costs of such reserve holdings, arbitrage activities will transmit the negative rates also to other rates in the economy. Ultimately, however, the capacity of central banks to implement negative rates is bounded by the ability of private market participants to transfer their reserve holdings into cash. Then, the *direct* costs associated with private cash holdings constitute the *physical lower bound* for negative policy rates (McAndrews, 2015; Rognlie, 2016). Where exactly this physical lower bound is depends on institutional factors like storage and insurance costs, which might vary internationally. Contrary to the pre-crisis consensus, however, recent experience has shown that negative policy rates have effectively removed the zero lower bound on short-term nominal rates. In fact, rough estimates suggest that the physical lower bound could go up to minus two percent, although this figure is subject to considerable uncertainty (Jackson, 2015; Schmiedel et al., 2012).

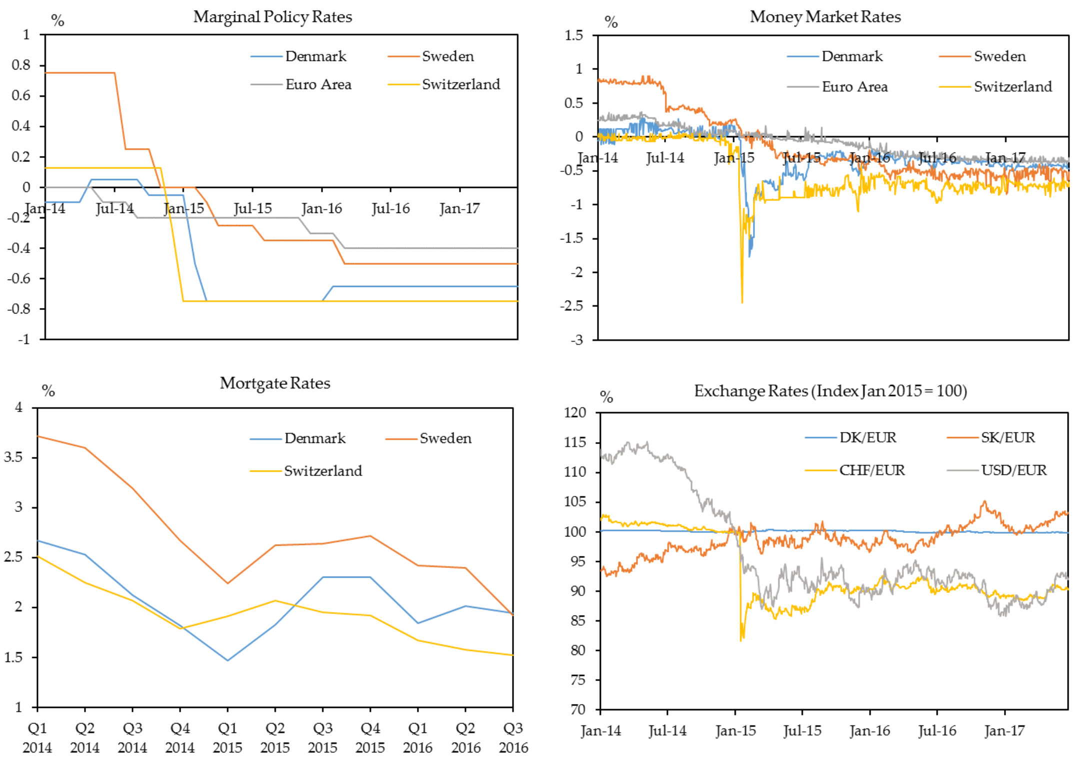

Figure 4.6.: Effects of negative policy rates ⋄ Marginal policy rates: certificate of deposit rate for Denmark, repo rate for Sweden, deposit facility rate for the euro area, and the midpoint of the target range for the 3-month Libor for Switzerland ⋄ Money market rates are the 3-month cash deposit rates ⋄ Mortgage rates are for fixed rate loans with maturities between 5-10 years ⋄ *Source:* National central banks, European Mortgage Federation, Datastream.

As displayed in Figure 4.6, *modestly* negative rates appear to have been transmitted to money market and capital market interest rates largely in the same way as positive rates – whereas the transmission to bank lending and deposit rates has only been partial (Jensen and Spange, 2015). The reason is that most banks are still reluctant to charge negative rates on retail deposits – presumably because they fear that retail depositors are more inclined to shift into cash, which would squeeze an important funding source for banks.[17] This leaves the exchange rate as one of the main variables through which negative policy rates might affect the economy. Actually, it seems that the negative rates contributed to the stabilization of the Swiss franc, when the SNB, in January 2015,

[17]This relative stickiness of retail deposits can be explained as follows: firstly, households and small businesses usually have lower excess liquidity and thus face lower storage and insurance costs than big corporations. Secondly, zero nominal rates might constitute a psychological threshold for retail depositors (Alsterlind et al., 2015).

abandoned the lower bound of its currency (which previously had been pegged at 1.20 CHF/EUR to curb an excessive appreciation of the franc). Given the complementary unconventional monetary policy measures, it is, however, very difficult to disentangle the precise impact of negative policy rates on financial and macroeconomic variables.

Potential Concerns about Negative Policy Rates Across all major advanced economies, the secular decline in both nominal and real long-term interest rates since the 1990s has put a structural strain on the traditional profits from financial intermediation (Summers, 2015; Eggertsson and Mehrotra, 2014). And while the average net interest income of euro area households has been largely unaffected by the ECB's accommodative policy since 2008, as the lower interest payments have mainly redistributed resources from net savers to net borrowers (ECB, 2016h), the downward rigidity of deposit rates may further accelerate the concerns about bank profitability – especially in an environment of negative rates.

Thus, there might be an *effective lower bound*, where further rate cuts due to negative effects on bank profitability risk to reverse the expansionary monetary policy stance. This *effective lower bound* could thus impose an earlier binding constraint for monetary policy than the *physical* one associated with the opportunity costs of holding cash (Coeuré, 2016). Brunnermeier and Koby (2016) call this the *reversal rate* of interest. It constitutes a threshold where bank profitability starts to decline, thereby reducing capital accumulation through retained earnings, which might trigger banks to eventually restrict lending. Indeed, profitability concerns seem to have induced Swiss, Danish and Swedish banks to actually *increase* their mortgage market rates once the policy rates fell into negative territory (see lower left panel in Figure 4.6).

This illustrates that, to the extent that banks cannot fully pass on negative rates to depositors, diminishing bank returns can actually reduce the availability of credit. Therefore, the real economic impact of lowering policy rates (further) into negative territory is likely to be more modest than a similar-sized change in the positive sphere. Generally, however, the extent to which bank profitability declines is determined by the degree to which banks' funding costs also fall. Hence, the central bank could mitigate the costs that drag on bank profitability by raising the threshold at which the negative deposit rate applies.[18] Albeit such reserve tiering enables further cuts into negative territory, it also reduces the transmission of negative deposit rates to market rates.

Irrespective of any tiered reserve remuneration, however, banks whose funding structure consists largely of retail deposits will suffer comparatively more from negative rates than those who focus on corporate banking. To compensate for such disadvantages, classical retail banks might change their business strategies and offer more fee-based services or try to substitute retail deposits with cheaper but less stable wholesale funding. In doing so, however, they may undermine financial stability.

Another frequently cited concern is that persistent low rates pose serious challenges for pension and insurance funds, which would be exacerbated by negative rates. As declining long-term yields tend to widen the negative duration gap between the assets and liabilities of these institutions, the latter will be inclined to take on inappropriately high risks (Borio and Zhu, 2008; Caballero et al., 2008; Becker and Ivashina, 2015). In addition, any attempt to increase the duration of their asset positions will cause a further downward pressure on long-term interest rates (Domanski et al., 2015). Overall, this points to the limits of negative policy rates over the long term. At some point, the policymakers' concerns about shrinking bank profits and financial instability may outweigh the benefits from higher asset values and stronger aggregate demand.

Experience with Negative Interest Rates in the Euro Area Since the ECB, in June 2014, has begun to charge negative rates on its deposit facility, no significant increase in euro area cash hoardings can be observed. In addition, the positive effects of lower funding costs and higher asset values seem to outweigh the adverse effects of reduced interest rate margins on banks' portfolios. That means so far that both the *physical* as well as the *effective lower bound* are beyond the current rate of the deposit facility (-0.4 percent).

With respect to credit availability, the ECB Bank Lending Survey (BLS) reveals that negative policy rates have led to a general increase in lending to households and non-financial corporations. In particular, negative rates are estimated to have contributed about one percentage point to the pick-up in corporate lending growth since June 2014 (Rostagno et al., 2016). Moreover, the ECB's Survey on Access to Finance for Enterprises (SAFE) documents an improvement in credit conditions for euro area small and

[18] In the Eurosystem, for instance, the €116 billion of required reserves are currently (June 2017) remunerated at the MRO rate of 0 percent, while about €542 billion of excess reserves are subject to the negative deposit rate of -0.4 percent. The SNB and the Riksbank also apply some kind of reserve tiering. For a detailed overview, see Jobst and Lin (2016) and Bech and Malkhozov (2016), respectively.

medium-sized enterprises (SMEs) that started shortly after the introduction of negative rates. Although this is of course a desirable effect of monetary policy accommodation, lending to smaller firms typically also entails a higher risk-taking for banks. In the aggregate, however, the ECB does not see excessive risk taking to be caused by its negative policy rate (Coeuré, 2016). Instead, at least two important factors have benefited euro area banks.

Firstly, the positive impact of negative rates on economic activity mitigated default risks and reduced the debt servicing costs of borrowers. Since this improves banks' credit quality, it facilitates lower risk provisioning. Secondly, lower interest rates lead to capital gains on banks' bond portfolios. And finally, the negative policy rates, by reinforcing the ECB's forward guidance and strengthening the portfolio rebalancing process, supported the effectiveness of the ECB's asset purchase program (Heider et al., 2017). Therefore, the ECB's negative deposit rate has so far proven to be effective in stabilizing inflation and mitigating the overall level of risk in the euro area economy. If, however, the period of negative rates persists much longer, the negative side effects of diminishing bank profitability could eventually prevail.

4.2. Theoretical Foundations

The theoretical foundations for the effectiveness of large-scale asset purchases by the central bank critically deviate from the traditional finance view with its emphasis on the expectations hypothesis of the term structure. More importantly, models involving the portfolio balance effect drop the assumption of perfectly flexible, frictionless financial markets and allow LSAPs to have a direct impact on the risk premia of financial assets. Recently, the literature on limited participation and preferred habitat has made valuable contributions in this field. In particular, the seminal paper of Vayanos and Vila (2009) offers a rigorous formal model of the portfolio balance effect that entails a mechanism by which supply and demand factors may have an effect on yields.

To illustrate the basic mechanisms, we will thus present a simplified, discrete-time version of the Vayanos-Vila model, drawing in large parts on Altavilla et al. (2015), Hayashi (2016), and Hamilton and Wu (2012).

4.2.1. Preferred-Habitat Theory

In order to show that LSAPs can have an effect on longer-term rates beyond the pure expectations hypothesis of the term structure, Vayanos and Vila's reformulation of the old preferred-habitat theory departs from the standard assumptions of no-arbitrage asset pricing.[19] Thus, the model includes two types of agents: *risk-averse arbitrageurs* and *preferred-habitat investors*. The latter could be regarded as preferring particular maturities or having a special demand for safety.[20] Yet if only preferred-habitat investors existed, asset markets would exhibit extreme market segmentation. Consequently, the role of risk-averse mean-variance arbitrageurs is to bridge the segmented markets, thereby rendering the term structure and asset markets essentially arbitrage-free.

Thus, with $z_t^{(n)}$ as the nominal share of n-period zero-coupon bonds that arbitrageurs choose to hold (relative to their net wealth), the risky per-period return on the bond portfolio is given by

$$\begin{aligned} R_{pf,t+1} &\equiv \sum_{n=1}^{N} R_{t+1}^{(n)} z_t^{(n)} = \sum_{n=1}^{N} \frac{P_{t+1}^{(n-1)} - P_t^{(n)}}{P_t^{(n)}} z_t^{(n)} \\ &= \sum_{n=1}^{N} \left[\exp\left(p_{t+1}^{(n-1)} - p_t^{(n)} \right) - 1 \right] z_t^{(n)} \end{aligned} \tag{4.1}$$

where $R_{t+1}^{(n)}$ is the one-period return on a n-period zero-coupon bond, purchased for the (log) price $p_t^{(n)}$ at time t and sold at $t+1$ for the (log) price $p_{t+1}^{(n-1)}$. To account for the different risk characteristics of euro area government bonds, Altavilla et al. (2015) extend the Vayanos-Vila framework by assuming that bonds, beyond interest rate risk, are subject to time-variant credit risk, ψ_t,

$$\psi_t = \gamma' f_t, \tag{4.2}$$

which itself is a function of the macroeconomic risk factors f_t. Since the latter follow an

[19] The preferred-habitat theory goes back to the seminal work of Culbertson (1957) and Modigliani and Sutch (1966).

[20] In practice, pension funds may serve as an example for preferred-habitat investors, as they try to match their structurally long-term liabilities with safe assets of equal duration.

AR(1)-process of the form

$$f_t = c + \Phi f_{t-1} + \epsilon_t, \quad \epsilon_t \sim N(0, \Omega), \tag{4.3}$$

and since all bond prices are an exponentially affine function of these risk factors,

$$p_t^{(n)} = \bar{a}_n + \bar{b}_n' f_t, \tag{4.4}$$

optimization calculus of the marginal bond market investor yields (see Appendix B.3 for the detailed derivations)

$$\varphi_t = \sigma \sum_{n=1}^{N} \Big(z_t^{(n)} (\bar{b}_{n-1} + \gamma) \Big). \tag{4.5}$$

This expression depicts the market price of risk. It is determined by arbitrageurs' risk aversion, σ, and by arbitrageurs' bond holdings at different maturities, $z_t^{(n)}$, weighted by the sensitivity of the bond price to macroeconomic risk factors, $(\bar{b}_{n-1} + \gamma)$. The crucial difference between this specification and most standard affine term structure models is that in the latter the risk price is taken as exogenous, whereas it is endogenously determined according to equation ⟨4.5⟩.

If the short rate process represents the only risk factor, then long-term bond holdings get a relatively larger weight in equation ⟨4.4⟩ than comparable short-term bonds, because the prices of long-term bonds react more strongly to fluctuations of the short rate than the prices of short-term bonds. Thus, the risk premium collapses to the standard term premium reflecting solely interest rate risk. It is shown in the appendix B.3 that, in this case, the term premium required by risk-averse investors to hold long-term bonds equals

$$rp_t^{(n)} = R_{t+1}^{(n)} - r_t = \bar{b}_{n-1}' \Omega \sigma \sum_{n=1}^{N} \Big(z_t^{(n)} (\bar{b}_{n-1} + \gamma) \Big) = \bar{b}_{n-1}' \Omega \varphi_t, \tag{4.6}$$

which itself is a function of the market price of risk, φ_t. The intuition is that bonds with a lower creditworthiness, i.e. with a high value of γ, command a higher compensation per unit of risk, because these bonds show a higher sensitivity to changes in the macroeconomic risk factors, f_t, and thus to the associated changes in the market-price of risk,

φ_t. To gain further intuition, we follow Gai and Vause (2006, p. 169) and decompose the factors determining the risk premium as illustrated in Figure 4.7.

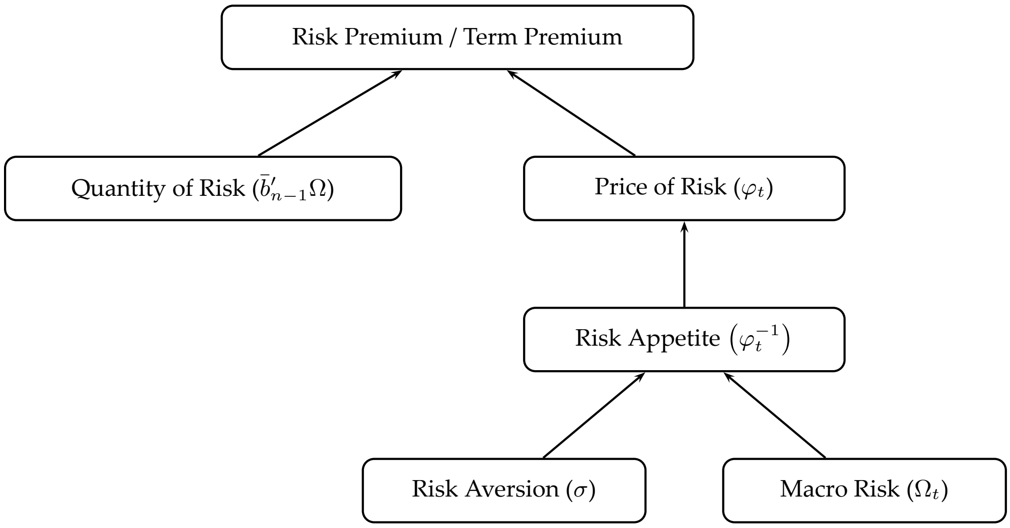

Figure 4.7.: Risk premium decomposition

At first sight, it appears that variations in risk premia can occur for several reasons. Risk aversion, however, is a deep parameter stemming from arbitrageurs' preferences over uncertain outcomes, which should be rather stable over time. If the quantity of asset-specific risk does not vary either, fluctuations in risk premia must reflect changes in macroeconomic uncertainty, its associated changes in the risk appetite and, eventually, its effect on the market price of risk. This is the central implication of equation ⟨4.6⟩: it states that the risk premium required by arbitrageurs equals the quantity of risk ($\bar{b}'_{n-1}\Omega$) times the market price of risk (φ_t).

On the other hand, the asset specific demand of preferred-habitat investors is given by

$$\xi_t^{(n)} = \alpha(n)\left(y_t^{(n)} - \beta^{(n)}\right) \qquad \langle 4.7\rangle$$

with $\beta^{(n)}$ as the intercept of the demand schedule, $y_t^{(n)}$ as the yield of a zero coupon bond with maturity n, and $\alpha(n)$ as a positive function of n. Specifically, $\alpha(n)$ denotes the price elasticity of preferred-habitat investors, which exceeds that of risk-averse arbitrageurs for bonds with particular maturities and/or certain risk profiles. Moreover, since the bond market clearing condition requires that the supply of bonds $S_t^{(n)}$ is met by the demand of preferred-habitat investors and arbitrageurs, it must hold that

$$S_t^{(n)} = \xi_t^{(n)} + z_t^{(n)}. \tag{4.8}$$

Rearranging ⟨4.8⟩ and substituting $z_t^{(n)}$ in equation ⟨4.5⟩ yields

$$\varphi_t = \sigma \sum_{n=1}^{N} \left(S_t^{(n)} - \xi_t^{(n)}\right)(\bar{b}_{n-1} + \gamma). \tag{4.9}$$

Other things equal, this expression for the general market price of risk indicates that central bank bond purchases, by reducing the supply of bonds on financial markets, compress required risk premia (cf. equation ⟨4.6⟩) and thereby also longer-term rates, and this effect increases with the bonds' sensitivity to the macroeconomic risk factors. Importantly, it also shows that the market price of risk is negatively dependent on the demand of preferred-habitat investors. That is, the higher the price-inelasticity of preferred-habitat investors for a particular bond, the higher will be the price increase when the central bank buys that particular bond.

Since we discuss the effectiveness of the APP with respect to yields, it is useful to express the arbitrageur's optimality condition in terms of bond yields rather than required risk premia. Hence, rewriting equation ⟨4.6⟩ in terms of the current bond yield, gives

$$\begin{aligned} y_t^{(n)} = {} & \frac{1}{n} E_t\left(r_t + r_{t+1} + \ldots\right) + \frac{1}{n} E_t\left(\gamma'(c + \Phi f_t) + \gamma'(c + \Phi f_{t+1}) + \ldots\right) \\ & + \frac{1}{n} E_t\left((\bar{b}'_{n-1} + \gamma')\Omega\varphi_t + (\bar{b}'_{n-2} + \gamma')\Omega\varphi_{t+1} + \ldots\right). \end{aligned} \tag{4.10}$$

4.2.2. Related Transmission Channels

The first term on the right hand side of equation ⟨4.10⟩ depicts the *signaling channel* of unconventional bond purchases, which can be inferred from the expected path of future short-term rates. The second component reflects the *portfolio balance channel*, i.e., more precisely, the credit premium of bonds, as evident from the parameter γ. Notably, a positive risk premium would also be required by *risk-neutral* investors, because of the smaller expected payoffs of bonds with a low degree of creditworthiness. Finally, the third component reflects the premium that is required by *risk-averse* investors as a compensation for a bond's uncertain payoff prior to maturity.

In this context, it should be seen that without the credit risk component ($\gamma = 0$), the second component drops out and the portfolio balance channel collapses to the classic *duration risk channel*. In other words, the general risk premium depicted in equation $\langle 4.10 \rangle$ can be understood as a compensation for the bond price fluctuations that emanate from the stochastic fluctuations in the macro factors (credit risk and interest rate risk). In this sense, the *credit risk channel* acts as an amplifier to the duration risk channel.

Yield Curve Effects In order to gain further insight on how central bank asset purchases affect interest rates in this model, it is useful to distinguish two polar cases with respect to arbitrageurs' risk appetite. In the first case, consider a very low level of macroeconomic uncertainty, a high risk appetite of arbitrageurs, and, according to equation $\langle 4.9 \rangle$, a low general market price of risk in the economy. In this set-up, arbitrageurs actively trade bonds with different risk profiles. If, for example, interest rate risk is assumed to be the only risk factor for government bonds, long-term government bond yields are determined by a term that can be interpreted as the average duration of arbitrageurs' portfolios. This implies that central bank asset purchases of bonds with specific maturities have an impact on the entire term structure, including maturities that are distant from the specific sector hit by the shock. This is the so-called *duration risk channel* of LSAPs, whose stylized effect on the yield curve is displayed in Figure 4.8. As the *credit risk channel* acts as an amplifier to the *duration risk channel*, it generates the same stylized yield curve effects.[21]

In the other extreme, when heightened financial market stress leads to excessive risk prices, for instance because arbitrageurs face binding capital constraints, then arbitrage activity becomes effectively inhibited.[22] Consequently, shocks to a particular maturity remain local to that segment of the yield curve and do not change the term structure in general. This is the *local supply channel* as outlined in Figure 4.9. Due to the preferred-habitat demand for long-term bonds, the yield curve exhibits a humped-shaped form as depicted by the dashed line in Figure 4.9.

In this respect, it has to be noted that the stylized term structure reactions of the dura-

[21] Given the stochastic nature of the credit risk component, the probability of a credit event increases with the time to maturity. Of course, in a more realistic framework, the credit-risk intensity of government bonds should be related to economic fundamentals (like the public debt ratio, for example).

[22] In a more realistic model, one could interpret arbitrageurs as banks. Then, arbitrage activity could be modeled as a function of bank capital, for instance. For a DSGE model of the portfolio balance effect that incorporates banks, see section 8.4 or Gertler and Karadi (2011).

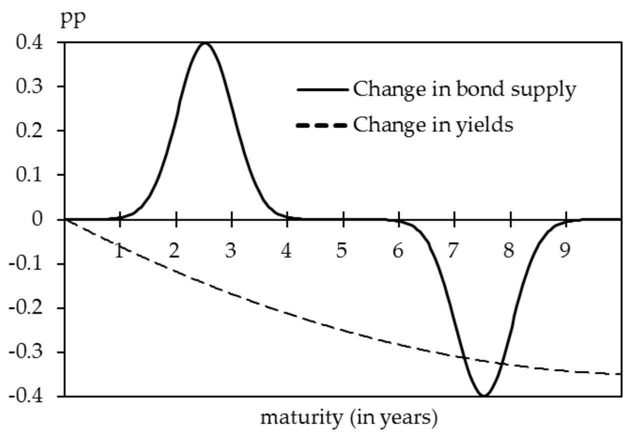

Figure 4.8.: Stylized effect of the duration/credit risk channel ◇ Own illustration based on Cochrane (2008) and Altavilla et al. (2015)

tion/credit and local supply channel are the two polar cases with respect to the arbitrage activity of the marginal bond market investor. For more realistic intermediate realizations of arbitrage activities, however, central bank bond purchases will result in a convex combination of those two effects.

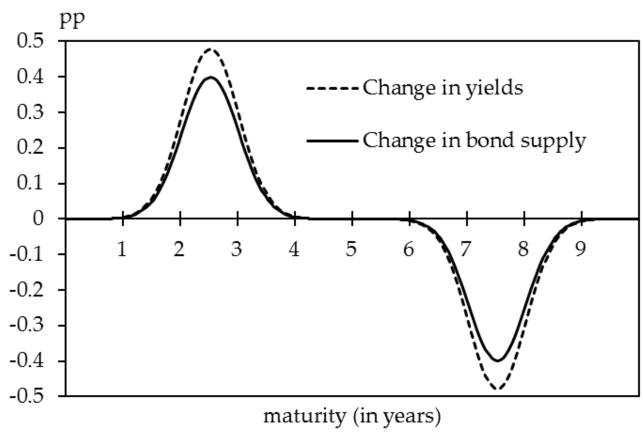

Figure 4.9.: Stylized effect of the local supply channel ◇ Own illustration based on Cochrane (2008) and Altavilla et al. (2015)

4.2.3. Concluding Remarks

The preferred-habitat model of the previous section can be viewed as a modern incarnation of the portfolio balance channel that Tobin has formulated already in 1969. Thereby, it combines important aspects of the Keynesian liquidity premium theory and the market segmentation theory, while it maintains useful features of the now standard arbitrage-free term structure models of Vasicek (1977) and Cox et al. (1985).[23] An advantage of the latter is that they can explain the continuous yield curve that is typical for modern financial markets, but which is at odds with the old preferred-habitat assumption of totally disconnected bond markets (Li and Wei, 2013). Furthermore, modern term structure models include a unique stochastic discount factor that prices duration risk consistently across the yield curve: since risk-averse investors require excess returns for bearing duration risk, those models can explain why longer-term rates regularly exceed the average future short rate. However, a shortcoming of arbitrage-free term structure models, the CCAPM, and most workhorse DSGE models is that any change in the supply of bonds that is unrelated to economic fundamentals has no effect on bond yields.[24] This is precisely the crucial innovation of the limited participation model of Vayanos and Vila (2009): although equilibrium spot yields can still be expressed as affine functions of common risk factors, changes in asset quantities do have an effect on bond yields.

Policy Implications The limited participation assumption embedded in the preferred-habitat theory of the term structure entails a risk premium that is a function of the risk bearing capacity of the marginal bond market investor. Consequently, shocks to available asset quantities affect the term structure and constitute a determinant of bond yields *in addition* to current and future short rates. This generates a rich set of implications for the transmission of monetary policy. Most importantly, it provides the opportunity for central bank purchases to affect long-term yields through a direct impact on risk premia. Whether and how these channels contributed to the effectiveness of recent unconventional monetary policy measures will be the subject of the following chapters.

[23] See also Issing (2007, p. 135).

[24] Piazzesi and Schneider (2007a) examine quantity effects in an otherwise standard CCAPM, whereby changes in the relative supply of different assets affect households' consumption and optimal portfolio decisions. However, they find only very weak quantity effects on asset prices in this framework.

5. Transmission Channels of Unconventional Monetary Policies

5.1. Portfolio Balance Channels

One of the key implications of the expectations hypothesis of the term structure is that monetary policy leaves risk premia completely untouched and affects long rates solely through its influence on short rates. This hypothesis contrasts with the *portfolio balance channel*, which is regularly referred to by central bankers to be the main theoretical justification for LSAPs. For instance, Bernanke in his speech given at the 2010 Jackson Hole Symposium, stated:

> "I see the evidence as most favorable to the view that such purchases work primarily through the so-called *portfolio balance effect*... Specifically, the Fed's strategy relies on the presumption that different financial assets are not perfect substitutes in investors' portfolios, so that changes in the net supply of an asset available to investors affect its yield and those of broadly similar assets (Bernanke, 2010, p. 9, italics added)."

The mechanism behind that channel can be described as follows: If the central bank purchases a particular security, it reduces the amount of that security in the portfolios of the private sector while simultaneously increasing the level of reserves. If private portfolios were in equilibrium before the transaction, the central bank has to offer a higher price for the purchased security in order for private investors to be willing to sell it. Put differently, central bank asset purchases bid up the price of an asset and lower its yield. Subsequently, as investors try to re-balance their portfolios, they transmit the yield effect towards assets that are imperfect substitutes.[1]

[1] For empirical evidence on the portfolio balance effect of LSAPs, see e.g. Gagnon et al. (2011b); Hamilton and Wu (2012); Joyce and Tong (2012); D'Amico et al. (2012); Greenwood and Vayanos (2014).

5.1.1. Duration Risk Channel

Duration Concept In order to explain the duration risk channel of central bank LSAPs, first it is necessary to understand the concept of duration more generally. As the basic bond pricing equation ⟨5.1⟩ reveals, lower spot rates lead to higher bond prices. Simultaneously, however, lower spot rates decrease the final value of the principal investment, since the reinvestment rates of future coupon payments have deteriorated. The duration of a bond thus signals the date when the *present value effect* equals the *income effect* of a given interest rate change (Spahn, 2012).

To see this more clearly, recall that a coupon-bearing bond can be regarded as a portfolio of zero-coupon bonds, where each coupon (c_j) represents the face value of a zero-coupon whose maturity corresponds to the time of the respective coupon payment, while the final zero-coupon with maturity n includes the principal (F) of the coupon-bearing bond. Then, the price of a coupon-bearing bond with n periods equals the portfolio price, and the basic bond pricing equation ⟨5.38⟩ can be rewritten as

$$\begin{aligned} P_t^{(n)} &= \sum_{j=1}^{n-1} \frac{c_j}{(1+i_{j,t})^j} + \frac{c_n + F}{(1+i_{n,t})^n} \\ &= \sum_{j=1}^{n-1} \frac{c_j}{\left(1+y_t^{(n)}\right)^j} + \frac{c_n + F}{\left(1+y_t^{(n)}\right)^n} \end{aligned} \qquad \langle 5.1 \rangle$$

where in the last row the potentially time-varying spot rates, $i_{j,t}$, were substituted by the bond yield $y_t^{(n)}$. This is a valid manipulation, if the coupons can be reinvested at a rate equal to the constant yield to maturity. Then, the yield to maturity of a coupon-bearing bond with maturity n is the constant interest rate that, when applied to all cash flows, justifies the quoted price of a bond (Cochrane, 2001, p. 348). The sensitivity of bond prices with respect to marginal changes in interest rates can be calculated by taking the derivative of bond pricing equation, i.e.

$$\frac{\partial P_t^{(n)}}{\partial y_t^{(n)}} = -\frac{1}{1+y_t^{(n)}} \sum_{j=1}^{n} \frac{j\, c_j}{\left(1+y_t^{(n)}\right)^j} \qquad \langle 5.2 \rangle$$

where it is assumed that the principal payment is included in the final coupon payment. Multiplying the above equation by minus one gives the general definition of duration:

$$D = -\frac{\partial P_t^{(n)}}{\partial y_t^{(n)}} = \frac{1}{1 + y_t^{(n)}} \sum_{j=1}^{n} \frac{j\, c_j}{\left(1 + y_t^{(n)}\right)^j}. \qquad \langle 5.3 \rangle$$

Note that in this definition of duration, discounting is done with the constant bond yield rate of interest – and not with potentially time-varying spot rates – yet the bond yield is of course a function of the time-varying spot rates.

For zero-coupon bonds, time to maturity is an adequate measure for the length of time a bondholder has invested money. For coupon-bearing bonds, however, maturity is an imperfect measure of that length of time because coupon payments occur prior to maturity. To remedy this deficiency, one can use the Macaulay duration.[2] Using ⟨5.3⟩, it can be calculated as

$$D_{mac} = D \frac{\left(1 + y_t^{(n)}\right)}{P_t^{(n)}} = \frac{\sum_{j=1}^{n} \frac{j\, c_j}{\left(1+y_t^{(n)}\right)^j}}{P_t^{(n)}}. \qquad \langle 5.4 \rangle$$

Keeping in mind that a coupon bond can be constructed as a portfolio of zero-coupon bonds, Macaulay's duration should be understood as the weighted average of the maturities of the underlying zero-coupon bonds, where the weight on each maturity is the present value of the corresponding zero-coupon bond using the yield of the coupon-bearing bond as the discount rate. (Campbell et al., 1997, p. 403). To calculate an average, this expression is then divided by the sum of the weights (which equals the bond price). As a consequence, Macaulay's duration is the only type of duration whose units are measured in time periods (usually years). This implies for zero-coupon bonds ($c = 0$) that Macaulay's duration equals maturity. For coupon-bearing bonds ($c > 0$), however, the duration is less than maturity, because the investor receives payments prior to maturity. The inverse relation between duration and coupon rates might not be readily apparent from equation ⟨5.4⟩, but can be easily inferred from basic economic reasoning: Macaulay's duration measures the number of years required to recover the investment costs of a bond. This time span declines with the coupon rate, because the more cash-flows are received in the short-term (due to higher coupon payments), the faster the investment costs of the bond will be recovered. In other words, duration *declines* with the coupon rate.

[2]After Macaulay (1938).

Two other important properties of duration can be highlighted by plugging the middle term of ⟨5.3⟩ into ⟨5.4⟩. This yields

$$D_{mac} = -\frac{\partial P_t^{(n)}}{\partial y_t^{(n)}} \frac{\left(1 + y_t^{(n)}\right)}{P_t^{(n)}} \qquad \langle 5.5 \rangle$$

which expresses Macaulay's duration as the negative elasticity of a coupon bond's price with respect to its yield (Campbell et al., 1997, p. 405). It underscores, firstly, that the duration of a bond, for constant coupons, is inversely related to its yield. And secondly, that for longer durations, marginal changes in yields generate stronger price effects. To sum up, duration risk comprises the following principles:

i. Duration is positively related to maturity: As maturity increases, bond prices become more sensitive to interest rate changes.
ii. Duration is negatively related to coupon rates: As coupon rates increase, bond prices become less sensitive to interest rate changes.
iii. Duration is negatively related to interest rates. As interest rates rise, bond prices become less sensitive to further interest rate changes.

Duration Risk and Asset Purchase Programs What has duration risk to do with the portfolio balance channel of central bank asset purchases? This might be best explained by considering a monetary policy operation that shortens the average maturity of the supply of bonds, but does not change the overall stock of bonds in the hands of the public.[3] In terms of the preferred-habitat model presented above, it shall be further assumed that arbitrageurs' risk bearing capacity is high, implying a low degree of asset market segmentation. Given these premises, the impact of such an operation on the yield curve is illustrated in Figure 4.8. Following Cochrane (2008), the solid line in Figure 4.8 depicts the change in the bond supply engineered by the central bank ($S_t^{(n)}$ in equation ⟨4.9⟩): it shows a reduction in the supply of longer-term bonds against an equal increase in the supply of short-term bonds. As can be inferred from equations ⟨4.4⟩ and ⟨5.5⟩, respectively, long-term bonds are more prone to interest rate risk than short-term bonds. Therefore, changes in the relative supply of long-term bonds affect bond

[3]Evidently, this resembles the Maturity Extension Program carried out by the Fed between 2011 and 2012, where the Fed reduced the supply of long-term Treasuries against an equal increase in the supply of short-term Treasury bills (see also section 4.1.3 – Examples of Qualitative Easing).

yields and expected returns by altering the amount of aggregate duration risk borne by arbitrageurs (see equation ⟨4.10⟩).

Interestingly, as indicated by the dashed line in Figure 4.8, the yields of *all* maturities decline, including the ones of short-term bonds, whose supply actually *increases*. The reason for this *downward shift* of the yield curve is that local supply effects are made global through the trading activities of arbitrageurs who integrate the different maturity markets. On the other hand, the *flattening* of the yield curve results from the fact that longer-term bonds carry more duration risk than short-term bonds. Hence, reducing the supply of longer-term bonds causes the price of that risk to decrease, which, according to equation ⟨4.9⟩ and ⟨4.10⟩, leads to a decline in the term premium and hence a drop in yields that increases with time to maturity. It should be noticed, however, that Figure 4.8 simulates the duration channel only qualitatively. Consequently, quantitative empirical evidence for this channel is reviewed in the subsequent paragraph.

5.1.1.1. Empirical Evidence for the US

Greenwood and Vayanos (2014) build on the preferred-habitat model of Vayanos and Vila (2009) but formulate all of their hypotheses in terms of the low-risk-aversion case of arbitrageurs. Thereby, they implicitly focus on the duration channel of bond supply variations.[4] In particular, they regress the spread of the 20-year Treasury yield to the 1-year yield on the ratio of publicly available Treasuries with remaining maturities greater than ten years. The latter is defined as a maturity-weighted debt to GDP measure, but SOMA holdings are not subtracted from their bond supply variable. Over a period from 1952-2007, Greenwood and Vayanos (2014) thus find that a decrease of one standard deviation in the share of Treasuries with maturities above ten years decreases the 20-year yield spread by about 40 basis points.

Because of the differences in empirical methodologies and samples across studies, it is difficult to compare these results with other estimates in the literature. Nonetheless, the estimates of Greenwood and Vayanos (2014) predict a significantly smaller effect of recent LSAPs than most other studies in this field.

Effects of US LSAPs The Fed, during its first two rounds of QE, acquired $900 billion[5] in Treasury bonds with an average maturity of approximately 6.5 years (see Table 1

[4]Other papers that found an effect of Treasury supply factors on bond yields are, e.g., Dai and Philippon (2006); Kuttner (2006); Garbade and Rutherford (2007); Greenwood and Vayanos (2010).
[5]$300 billion under LSAP1 and $600 billion under LSAP2

in D'Amico and King, 2013, p. 429). Taking the corresponding duration to be 5 years and GDP to be $14 trillion, the estimates of Greenwood and Vayanos suggest that those operations lowered 20-year Treasury yields by about 13 basis points.[6]

While Greenwood and Vayanos (2014) use aggregate data on the amount of outstanding Treasury debt, D'Amico et al. (2012) run a time-series regression using security specific data, which enables them to subtract SOMA holdings from total public debt. Moreover, their refined data set allows them to infer detailed observations about both the supply and duration channel of LSAPs. Based on a sample from December 2002 to October 2008, they estimate that the duration effect of the Fed's first two LSAPs lowered the yields on 10-year Treasury bonds by about 22 basis points. More precisely, they find that the duration effect of LSAP1 (which totaled $300 billion) lowered the 10-year Treasury yield by 12 basis points, whereas LSAP2 (which totaled $600 billion) lowered this yield by only 10 basis points.

At first sight, it seems puzzling that the second program, despite being twice as large than the first, had a smaller impact on long-term yields – especially since the share of Treasuries held by private investors exhibited a noticeably larger decline during the second program (displayed in the top panel of Figure 5.1), while both programs had a comparatively weak impact on average duration (see the lower panel of Figure 5.1). One reason for this seemingly unintuitive result could be that arbitrageurs' risk bearing capacity was unduly low during the first program, which, consistent with the preferred-habitat theory, would explain the differences in the relative effectiveness across both operations.

The time-series results of D'Amico et al. (2012) for the duration effect of LSAP1 are broadly in line with those of Gagnon et al. (2011b). Over a period from January 1985 to June 2008, the latter run a monthly time-series regression and find, after controlling for business cycle factors and uncertainty about economic fundamentals, that the $300 billion in Treasury purchases lowered 10-year Treasury yields by about 12 basis points.[7]

[6] The bond purchases of $900 billion imply a reduction in the average duration of outstanding Treasury debt of about $0.9 \times \frac{5}{14} \approx 0.32$ years (see Greenwood and Vayanos, 2014, p. 685). Since a reduction of one standard deviation amounts to a reduction in average duration of about 1 year (and a corresponding decline in 20-year Treasury yields of about 40 basis points), the programs' impact on 20-year Treasury yields equals $0.32 \times 40 \approx 13$ basis points.

[7] Gagnon et al. (2011b) document that LSAP1's total volume of $1,725 trillion (including $1,25 trillion in agency MBS and $175 billion in agency debt) equaled approximately $850 billion in terms of '10-year equivalents' (or roughly 6 percent of 2009:Q4 nominal GDP). The concept of '10-year equivalents' is the par amount of 10-year Treasury bonds that would have the same duration as the actual portfolio of assets purchased. Mathematically, '10-year equivalents' are calculated as follows: 10-year equivalents = par value of portfolio × average portfolio duration / duration of 10-year Treasury note. Since the $300

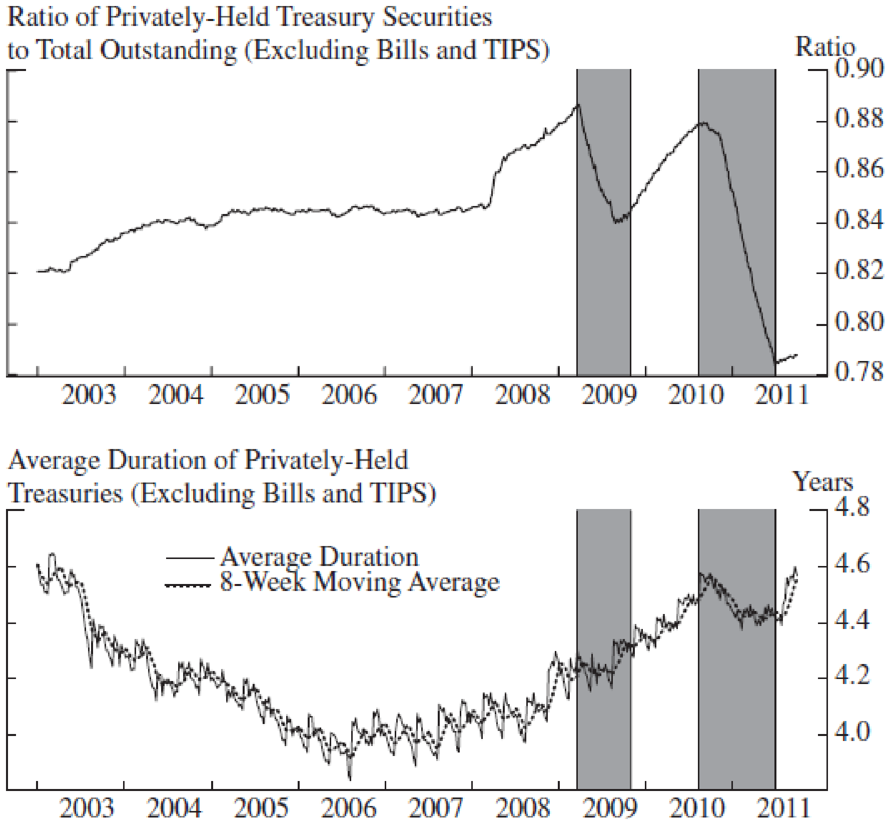

Figure 5.1.: Privately-held nominal US Treasuries and average duration ◇ The shaded areas indicate the first two LSAPs programs in the US. ◇ *Source*: D'Amico et al. (2012, p. 431).

Besides their time-series study, Gagnon et al. (2011b) also use an event-study approach to evaluate LSAP1. With a one-day window around eight event dates (from November 25, 2008 to November 4, 2009), they find that the 10-year Treasury yield declined by 91 basis points. Scaled to the $300 billion in Treasury purchases, this implies a reduction of 16 basis points.[8] These figures are largely confirmed by the event-study estimates of Cahill et al. (2013), who, depending on the parameter specification, quantify the duration effect of LSAP1 to lie between 11 and 23 basis points (when interpreted as an

billion of Treasury purchases roughly correspond to a $169 billion shock in terms of privately held 10-year equivalents (or roughly 1.2 percent of 2009:Q4 nominal GDP; see Li and Wei, 2013, p. 28), the OLS estimates of Gagnon et al. (2011b) imply that 10-year yields declined by about 12 basis points.

[8]Krishnamurthy and Vissing-Jorgensen (2011), by using a subset of the event dates of Gagnon et al. (2011b), find only minor evidence for the duration channel of LSAP1. However, they find positive evidence for the prepayment risk channel of agency MBS purchases, which is essentially a sub-channel of the duration risk channel.

unexpected $300 billion purchase program), and that of LSAP2 between 1 and 14 basis points.

The tendency that time-series estimates based on pre-crisis data generally lie below the estimates obtained in event-studies, suggests that the former consistently underestimate arbitrageurs' risk aversion, and thus also underestimate the potential effectiveness of central bank asset purchases – especially during the heydays of a financial crisis.

In order to prevent some caveats of time-series regressions – such as endogeneity issues or small sample biases – Li and Wei (2013) estimate an arbitrage-free term structure model to evaluate the effectiveness of US LSAPs. Using a sample from March 1994 to July 2007 on the private holdings of Treasury securities and agency MBS, they find that the total $1,725 trillion asset purchases lowered 10-year Treasury yields by 99 basis points. Accordingly, the $300 billion Treasury purchases contributed with about 17 basis points to this decline in yields.[9] It is notable that, in spite of the different methodology and sample period of Li and Wei (2013), their affine term structure model generates estimates that are in the same ballpark as most event-study estimates (e.g. Gagnon et al., 2011b; Cahill et al., 2013), yet differ considerably from the evidence found in the time-series literature (e.g. D'Amico et al., 2012; Greenwood and Vayanos, 2014). This may lend further support to the hypothesis that time-series studies understate the effectiveness of LSAPs during times of financial strains.

Effects of US Maturity Extension Programs (MEPs) On September 21, 2011, the FOMC announced its intention to extend the average maturity of its bond portfolio by 25 months to about 100 months by the end of 2012.[10] To achieve this goal, the FOMC purchased $400 billion of Treasury securities with remaining maturities between six and thirty years. In contrast to previous programs, however, the Fed did not issue reserve to finance the purchases. Instead, the FOMC sold an equal amount of Treasury securities with remaining maturities between three months to three years, such that the MEP changed only the composition, but not the size of the Fed's balance sheet. In this regard MEP was actually a new version of *Operation Twist* which had been implemented in the early 1960s (a thorough review of this episode is given in the following paragraph). Figure 5.2 depicts some preliminary descriptive evidence for the effectiveness of MEP.

The white squares show the US Treasury yield curve one day before and the black

[9] If LSAPs are interpreted as a sequence of supply shocks, Li and Wei (2013) find somewhat smaller effects of LSAP1 (about 60 basis points for 10-year Treasury yields.)

[10] see the FOMC (2011a) press release.

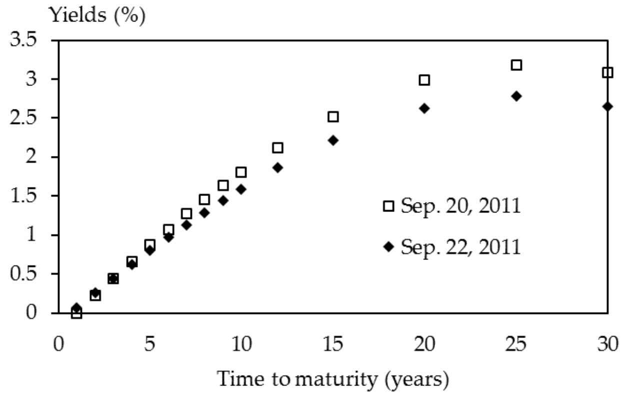

Figure 5.2.: US Treasury yield curves around MEP announcement date ⋄ *Source*: US Department of the Treasury

diamonds one day after the MEP announcement. As expected, yields of longer maturities experienced a downward shift, while the yields of shorter maturities did not move significantly in response to MEP. Indeed, the fact that yields up to three years show almost no reaction to changes in the supply of bonds with corresponding maturities, may reflect the close substitutability between short-term bonds and reserves at the zero lower bound of the nominal interest rate.[11]

On June 20, 2012, the FOMC decided to continue the initial MEP through the end of the year at the same pace resulting in the purchase, as well as sale and redemption, of about $267 billion of Treasury securities (see FOMC, 2012). The purchases, generally referred to as MEP2 in the literature, were distributed across five maturity buckets using the same approximate weights as that of the previous program (see Federal Reserve Bank of New York, 2012).

Coupon-Bearing Treasury Securities by Remaining Maturity				TIPS
6 – 8 Years	8 – 10 Years	10 – 20 Years	20 – 30 Years	6 – 30 Years
32%	32%	4%	29%	3%

Table 5.1.: Maturity distribution of US treasury purchases under MEP ⋄ The 10-year Treasury note is included in the 8 – 10 year sector. ⋄ TIPS weights are based on unadjusted par amounts. ⋄ *Source*: Federal Reserve Bank of New York.

[11] A very close inspection of Figure 5.2 in fact reveals that yields up to 3 years increased slightly, while yields above 3 years decreased in response to the MEP announcement. This effect might be driven by the increase in the supply of bonds with maturities between 3 months and 3 years.

Regarding MEP1, Hamilton and Wu (2012) find that the program would have lowered 10-year Treasury yields by 14 basis points while raising the 6-month yield by an equal amount. These countervailing effects on short- and long-term interest rates occur only if short-term rates are away from the zero lower bound, however. Thus, in normal times, by selling short-term bonds and purchasing long-term bonds, monetary policy may succeed in flattening the yield curve, but it has not much potential in bringing down the overall level of interest rates. This may change if short-term rates are at the zero lower bound, because selling short-term bonds has negligible effects on yields in such an environment. Accordingly, at the zero lower bound, Hamilton and Wu (2012) estimate that purchasing $400 billion of long-term Treasury securities against an equal amount of short-term securities (or reserves) could reduce 10-year rates by about 13 basis points without raising short-term yields.

Indeed, when the Fed conducted the MEPs (2011–2012), the short-term policy rate was at its zero lower bound. In addition, even at the start of the program, private market participants had little reason to expect a rate increase in the near future, as the Fed on August 7, 2011, i.e. one month before the announcement of MEP1, had warranted to keep "exceptionally low levels for the federal funds rate at least through mid-2013" (FOMC, 2011b). That short-term rates reacted little to the Fed's MEP is verified by Li and Wei (2013), who document that yields with maturities less than two years showed no reaction, while 10-year Treasury yields declined by 25 basis points. The estimates of Cahill et al. (2013) with respect to the duration effect of MEP1 and MEP2 lie in a range between $22 - 35$ basis points and $4 - 18$ basis points, respectively. Overall, the empirical evidence seems to support the MEP's effectiveness in reducing longer-term interest rates through the duration channel. Moreover, in terms of dollars spent, it seems that MEP was equally effective as LSAP1 and more effective than LSAP2.

Effects of US Operation Twist in the 1960s The 'Operation Twist' of the 1960s serves as another natural experiment for the duration channel sketched out in Figure 4.8. In 1960-61, the US, as part of the Bretton-Woods System of fixed exchange rates, was facing both a recession and a balance of payments deficit. This constellation confronted the Fed with a fundamental trade-off; from an internal perspective, the recession called for a lowering of the short-term policy rate; externally, however, a lower US short-term rate would have accelerated the capital outflow – especially since most European interest rates were already higher than the concurrent US rates.

As a consequence, the incoming Kennedy administration persuaded the Fed to implement what came to be known as 'Operation Twist'. Besides its name, however, the operation had nothing to do with the popular twist dance of the time. It was rather established as a concerted action between the Fed and the US Treasury with the goal to flatten (to 'twist') the yield curve. The idea was that domestic demand was primarily determined by longer-term rates, whereas the balance of payments and international gold flows was driven by cross-country differentials in short-term rates.

Hence, the Fed began to sell off short-term notes and purchased longer-term government bonds (see Figure 5.3), while the Treasury increasingly shortened the average duration of newly issued government debt. Together, both policies shortened the average

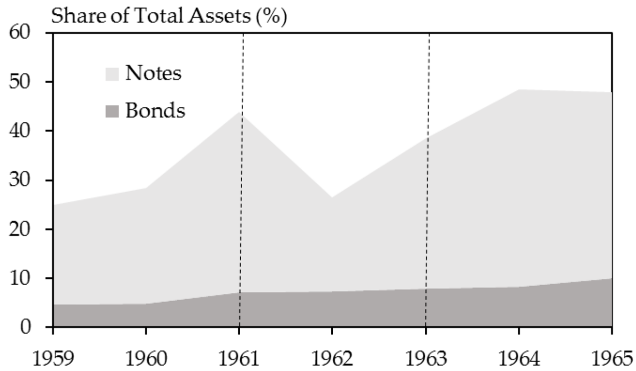

Figure 5.3.: Fed holdings of US government securities ◇ Dashed vertical lines depict the period of Operation Twist. ◇ *Source*: Board of Governors of the Federal Reserve System, Annual Reports, various years.

duration of government bonds in the hands of the public, which, according to the duration channel, should have lowered longer-term rates relative to short-term rates.[12] And indeed, the spread between long- and short-term yields declined moderately throughout the course of the program (see Figure 5.4).

However, the empirical investigations by Modigliani and Sutch (1966, 1967) find no evidence that the changes in the maturity structure of government debt had any significant effect on long-term interest rates. Instead, Modigliani and Sutch (1966, 1967) attribute the decline in the yield spread to the successive increases in ceilings on US time deposits (Regulation Q). Since the lifting of interest rates under Regulation Q – consistent with the preferred-habitat hypothesis – implied a relaxation of arbitrage constraints, it should have reduced the effectiveness of Operation Twist on long-term inte-

[12]During the course of the program (from 1961-63), the Fed ultimately purchased about $8.8 billion of longer-term bonds, while its short-term positions were reduced by about $7.4 billion (see Figure 5.3 as well as Table 2 in Meulendyke, 1998, p. 40).

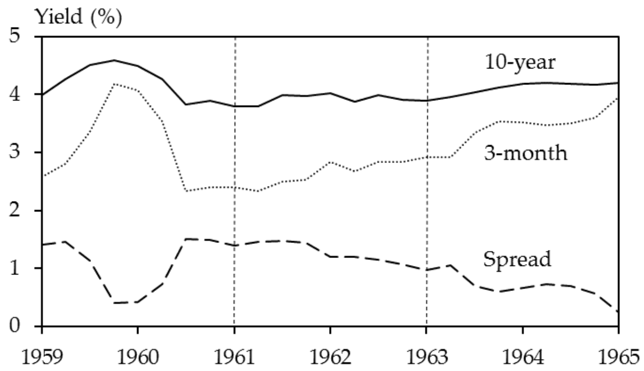

Figure 5.4.: US government bond yields ◇ Dashed vertical lines depict the period of Operation Twist. ◇ *Source*: Federal Reserve, Datastream.

rest rates.[13] Additionally, the declining yield spread could simply reflect the behavior of the short-term rate, which was raised in line with the economic recovery that started in April 1961 (compare the upward trend of the dotted line in Figure 5.4).

Moreover, Solow and Tobin (1987) stress that the average maturity of outstanding Treasury debt rose substantially right after the termination of Operation Twist. Thus, debt management by the Treasury potentially undercut any effects that could have followed the relatively small intervention of the Fed. A similar argument is made by Tobin (1974, pp. 32-33) and Bernanke et al. (2004), who claim that Operation Twist was too impersistent to have generated a significant impact on longer-term rates. Based on this evidence, the conventional view today is that Operation Twist was a rather unsuccessful experiment of US economic policy.

In contrast to the conventional view, however, new research by Swanson (2011) suggests that Operation Twist was more effective than initially thought. Swanson argues that low-frequency regressions – like the quarterly regression model of Modigliani and Sutch (1966, 1967) – are not suitable for detecting interest rate movements based on maturity manipulations of outstanding government bonds.[14] Using a higher-frequency event study approach, Swanson finds that Operation Twist had a statistically significant effect on longer-term rates; concerning 10-year US Treasury yields, he estimates that Operation Twist cumulatively lowered them by about 15 basis points. Nonethe-

[13]The pessimistic conclusions of Modigliani and Sutch (1966, 1967) were questioned by other studies, however; see for example Wallace (1967) or Holland (1969).

[14]This suggestion is underscored by Holland (1969) who uses a higher-frequency (monthly) regression model and finds a positive impact of Operation Twist on long-term US interest rates.

less, Swanson agrees with the conventional view that Operation Twist had at best only very moderate effects on the activity of the US economy.

5.1.1.2. Empirical Evidence for the UK

Unconventional asset purchases in the UK differed from the US LSAPs in various ways. In January 2009, the Treasury Department authorized the BoE to set up an Asset Purchase Facility (APF) to buy high-quality private sector instruments. Until July 2009, the APF had thus purchased commercial papers, corporate bonds and asset-backed securities for about £3 billion (Bank of England, 2015). To shield the BoE balance sheet against possible losses emanating from these securities, the APF was established as a separate legal entity with comprehensive indemnity from the UK Treasury. This kind of explicit fiscal backing is rather unique compared to other jurisdictions: neither the Fed nor the ECB receives comparable insurance from fiscal authorities.

The aim of the APF was to promote credit creation and to increase liquidity in disturbed financial market segments. Initially, the purchases of private sector instruments were financed by issuing Treasury bills, that is, *qualitative easing*. Even at the outset, however, the Treasury indicated the possibility that the facility could turn into an explicit monetary policy instrument, namely by financing purchases with reserves instead of Treasury bills. On March 5, 2009, the MPC decided to use this option and announced a reserve-based purchase program of £75 billion of UK Treasury bonds (gilts). In doing so, the BoE effectively moved from *qualitative easing* to *quantitative easing*.

Since then, gilt purchases have been gradually expanded over time: the first asset purchase program (APF1) finally amounted to £200 billion, while a second program (APF2), which was conducted from October 2011 to July 2012, added another £175 billion. Then in August 2016, amid uncertainty over the 'Brexit' process and concerns about inflation and economic growth, the MPC decided to reactivate its gilt purchases by £60 billion and to purchase corporate bonds up to £10 billion (Bank of England, 2016). Hence, the BoE's total stock of gilts sums up to £435 billion, representing approximately 25% of the free float of gilts (as of July 2016).

Effects of APF Due to the forward-looking nature of financial markets, most of the impact of asset purchases on yields is likely to occur when expectations are formed, rather than when the purchases are actually made. Therefore, the BoE's repeated recourse to the asset purchase facility since 2009 casts doubt on the applicability of event-studies, at least for later announcements of this monetary policy tool. The reason is that once market participants learned how the BoE used asset purchases conditional on the state of the economy and the outlook for inflation, they began to expect upcoming operations ahead of the formal announcements. As a consequence, if asset purchases are widely anticipated, event-studies that confine the assessment around formal announcements risk to underestimate the overall impact of such programs.

Arguably, however, the initial asset purchase announcements contained enough news to justify an event-study approach. In this respect, the movement of the UK gilt yield curve around March 05, 2009 is quite striking (see Figures 5.5 and 5.6). Within a two-day

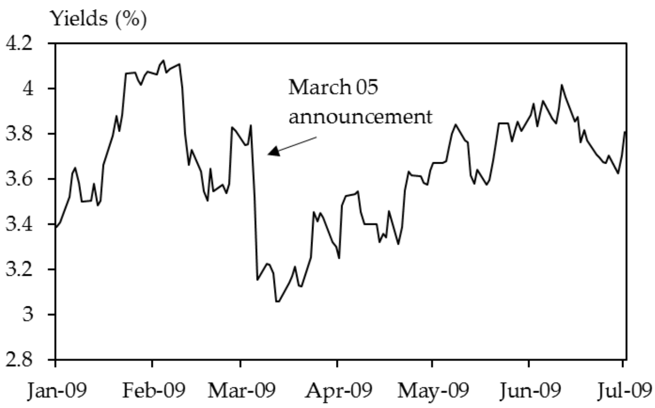

Figure 5.5.: 10-year gilt yield ◇ *Source*: Datastream, Bank of England.

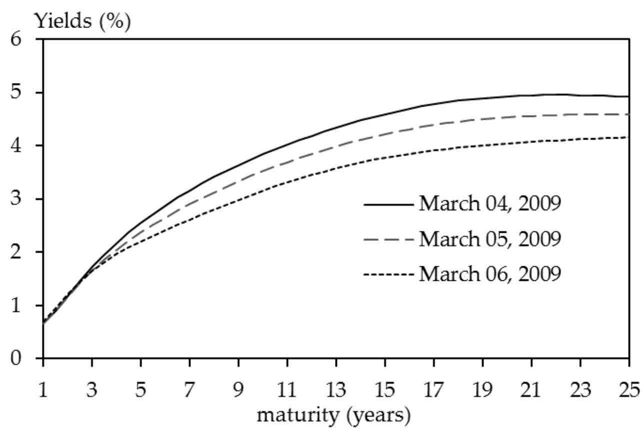

Figure 5.6.: Gilt spot yield curves around APF1 (March 05, 2009). ◇ *Source*: Datastream, Bank of England.

window around the announcement date, medium- and long-term yields fell between 40 and 90 basis points (see also Meier, 2009). These observations are broadly in line with other empirical estimates of the BoE's asset purchase scheme. Joyce and Tong (2012), for example, conducted an event-study around the six announcements for APF1 listed in Table 5.2.

Date	Event Description
Feb. 11, 2009	MPC Inflation Report: strong indication of an upcoming asset purchase program (MPC, 2009d).
Mar. 05, 2009	MPC statement: announcement to purchase £75 billion in gilts with remaining maturities between 5 and 25 years financed by reserve creation. Additional announcement to lower the policy rate from 1% to 0.5% (MPC, 2009e,a).
May 07, 2009	MPC statement: announcement to extend asset purchases facility by £50 billion to $125 billion (MPC, 2009f).
Aug. 06, 2009	MPC statement: announcement to extend asset purchase facility by another £50 billion and extension of eligible maturities to a minimum residual maturity of 3 years (MPC, 2009b).
Nov. 05, 2009	MPC statement: announcement to extend asset purchase facility to £200 billion (MPC, 2009c).
Feb. 04, 2010	MPC statement: announcement to maintain the amount of the asset purchase facility at £200 billion. If conditions warrant, indication of possible further extensions (MPC, 2010).

Table 5.2.: Event dates for APF1 ⋄ *Source:* Joyce and Tong (2012).

Using intraday data on the whole cross-section of gilts,[15] they find that medium- and long-term yields on average declined by about 98 basis points.[16] As shown in Table 5.3, while the impact of asset purchases declined over time, longer-term yields generally declined more than short-term yields. Other things equal, this appears to be positive evidence for the duration risk channel, which operates when the decline in yields is monotonically increasing with maturity. On the other hand, Table 5.3 also reveals that the bulk of the yield reaction is skewed towards gilts with remaining maturities between 15 and 20 years (-119 resp. -116 basis points), whereas yields with maturities above 25 years declined by only 84 basis points. Given that the BoE acquired a relatively big share of gilts in the maturity segment of 15 and 20 years, this points to a more significant impact of the local supply channel. Based on the dataset of Joyce and Tong (2012), the following simple cross-sectional regression attempts to shed further light on the relevant

[15]Joyce and Tong (2012) compile a dataset using gilt price quotations from Tradeweb (an online trading platform for fixed income securities) with a frequency of five minutes.

[16]Calculated as the average sum of the last row in Table 5.3, excluding securities with remaining maturities below five years (the second column).

Date	UKT, 5% 2012	UKT, 4.75% 2015	UKT, 4.75% 2020	UKT, 5% 2025	UKT, 4.75% 2030	UKT, 4.5% 2042
Feb. 11, 2009	-35	-34	-30	-17	-17	-15
Mar. 05, 2009	5	-47	-45	-77	-74	-44
May 07, 2009	-4	-10	-7	-10	-9	-6
Aug. 06, 2009	-4	-12	-14	-27	-28	-28
Nov. 05, 2009	7	10	10	7	6	5
Feb. 04, 2010	4	5	6	5	5	4
Sum of dates	-26	-88	-81	-119	-116	-84

Table 5.3.: Yield changes around APF1 event dates (basis points) ⋄ The windows around the respective event dates comprise time periods between 1 hour and one day. ⋄ *Source:* Tradeweb; Joyce and Tong (2012, p. 362), Table 3.

transmission channels of APF1

$$\Delta y(gilt_i) = \sum_{j=1}^{3} \beta_j LS_{i,j} + \beta_4 DUR_i. \qquad \langle 5.6 \rangle$$

Following Joyce and Tong (2012), $LS_{i,j}$ is a three-dimensional vector capturing the local supply channel, whereas the variable, DUR_i, tries to measure the duration risk channel. The first variable measuring the local supply channel is an indicator variable that takes the value of 1 if a specific gilt is included in the purchase range and zero otherwise. Since the inclusion of a gilt into the purchase range is expected to lower its yield, the regression coefficient should carry a negative sign. The second variable takes the value of 1 if a gilt was added to the purchase range in the latest policy announcement, -1 if it was excluded, and zero otherwise. Since gilts that have been newly added to the purchase range are expected to experience a relative strong decline in yields, its coefficient should carry a negative sign. The third variable, the duration gap, is the difference in years between the duration of a gilt that is *not* included in the purchase range and the gilt with the closest duration that *is* included in the purchase range. Under the premise that the duration gap is a proxy for substitutability across gilts, yields should decrease with the duration gap. Finally, if the duration risk channel matters, changes in yields will increase in duration, that is, the coefficient β_4 in regression ⟨5.6⟩ is expected to carry a positive sign.

Table 5.4 summarizes the regression results, and while all significant coefficients have the expected sign, the estimates further suggest that the local supply channel was more important than the duration channel for the BoE's first asset purchase program. The relatively strong impact of the more narrow local supply channel is conceivable at least on two grounds. Firstly, at this early stage of the financial crisis, financial markets

Change in yields (bp)	Feb. 11, 2009	Mar. 05, 2009	Aug. 6, 2010
Constant	-19.8***	-18.1**	-3.1
Purchase range† (β_1)	-14.1***	-14.8**	-8.7**
Newly eligible (β_2)	n/a	-19.4***	-5.0***
Duration gap (β_3)	0.3	3.1**	-0.3
Duration (β_4)	-0.1	-2.0***	-0.7***
Number of obs.	30	32	35
Adj. R^2	0.91	0.96	0.85

Table 5.4.: Regression estimates for key announcements of APF1 (basis points) ⋄ Asterisks denote statistical significance at the ***1 percent, **5 percent, and *10 percent level ⋄ †In the case of the February announcement, this denotes the expected purchase range. ⋄ *Source:* Bank of England, Joyce and Tong (2012, p. 367).

were still heavily impaired. Secondly, the BoE, during the course of APF1, acquired approximately 30% of the free float of gilts (see also Table 5.5). In other words, limits to arbitrage and the sheer size of the asset purchase scheme are likely to have contributed to the relative importance of scarcity-related channels.

Maturity range	3-10 years	10-25 years	above 25 years
	40%	50%	15%

Table 5.5.: APF1 size relative to the free float of gilts ⋄ *Source*: UK Debt Management Office, Bank of England

Although the methodological issues render it difficult to come up with a robust estimate for the relevant transmission channels, the study by McLaren et al. (2014) attributes between 42–62% of the total variation in gilt yields to the local supply channel. Since the duration risk channel in turn accounts for about 32–38%, they conclude that the duration channel played only a subordinate role during APF1.[17]

In addition, McLaren et al. (2014) also assess the BoE's subsequent asset purchase facility (APF2). For the announcement on February 09, 2012, they document that the duration channel actually led to a *rise* in longer maturity gilt yields. According to the logic of the duration channel, this means that the BoE acquired less aggregate duration risk than market participants had previously expected.

[17] Breedon et al. (2012) confirm this result by showing that even though the BoE acquired long duration assets, the maturity of outstanding debt rose, as the DMO was issuing an even larger proportion of longer-term gilts.

5.1.1.3. Empirical Evidence for the Euro Area

A detailed event study assessing the effectiveness of the ECB's asset purchase program is given in chapter 6. There, we firstly find that the large-scale asset purchases substantially lowered the government bond yields of various euro area countries, while showing significant cross-country differences. Secondly, the program involved rather strong spillover effects to other asset classes. Overall, this leads to the conclusion that the duration and credit risk channel were amongst the dominant transmission channels of QE in the euro area.

5.1.1.4. Policy Implications

In response to the financial crisis, central banks around the globe have acquired long-duration assets by issuing central bank reserves. Other things equal, this should have lowered the amount of *aggregate duration risk* in the hands of the public. With less duration risk to be held in the aggregate, market participants in turn should require a lower premium to hold that risk, causing bond prices to rise and yields to fall. Moreover, the duration channel predicts that official asset purchases lead to a downward shift of the entire yield curve, even if the central bank accompanies the decrease in the supply of long-term bonds with an equivalent increase in the supply of short-term bonds (see Figure 4.8). Since in this event the amount of *aggregate* duration in the market also decreases, the yields of all bonds decline, including the ones of short-term bonds, whose supply *increases*. Nevertheless, with long-term bonds being more exposed to duration risk than short-term bonds, central bank asset purchases should lead to a larger reduction of the yields on long-term bonds, thereby shrinking the term spread. Put differently, when the central bank removes a given amount of duration risk by purchasing ten-year bonds, it could achieve the same effect by purchasing a smaller amount of thirty-year bonds.

Another important issue is whether the duration channel is confined to a particular asset class (e.g. sovereign bonds), or if its yield impact spills over to other fixed-income markets (e.g. corporate bonds). Based on the preferred-habitat theory laid out in section 4.2, the answer critically relies on the behavior of the marginal bond market investor. In principle, if the demand of preferred-habitat investors is limited to sovereign bonds, then sovereigns should experience a stronger price effect than corporates. If, however, limits to arbitrage are not prohibitively high, marginal bond market investors will actively respond to the relative yield changes and actively re-balance their portfolios. Consequently, LSAPs of even a few specific bonds affect the risk pricing and term premia for a wide range of securities. If no other frictions exists, i.e. investors have no special preferences for any particular type of assets, then the duration channel implies that fixed-income securities with identical risk-profiles should all be equally affected by central bank LSAPs.

This statement has to be qualified somewhat with respect to LSAPs in the euro area. Here, the significant heterogeneity across euro area sovereign bonds with the same maturity is likely to be explained by the different degrees of *credit risk* (see Table 6.3). In principal, this implies that, in order to maximize the APP's overall effectiveness, asset purchases in the euro area should be geared towards the jurisdictions with the lowest credit quality. However, since this would fall in the realm of monetary financing of Member States, the share of purchases is determined by the ECB's capital key.[18] Notably, this analysis offers the following lessons for the implementation of LSAPs:

i. LSAPs have a stronger effect on yields of longer durations.
ii. LSAPs affect the yields of all nominal assets, including sovereign bonds, corporate bonds, and asset-backed securities.
iii. The heterogeneous effects of the LSAPs on euro area sovereign yields are largely driven by the credit risk channel.

5.1.2. Local Supply Channel

Conceptually, it is possible to separate the *duration channel* from the *local supply channel* by means of the risk-bearing capacity of arbitrageurs. While an important feature of both channels is the assumption of imperfect asset substitutability, for the local supply channel to work, market segmentation must be sufficiently high. Under such circumstances, an asset purchase program that shortens the maturity structure of potentially risk-free bonds generates a relatively large drop in the yields of the targeted maturity segment (or asset class), because the central bank must pay a high excess bond price for preferred-habitat investors to be willing to sell them. The stylized effect of such a *local supply channel* is displayed in Figure 4.9.

Although longer-term yields do decline considerably, in contrast to the duration risk channel (cf. Figure 4.8), short-term yields actually increase as a result of the larger sup-

[18]With respect to the four countries considered above, this means that approximately 26% of the monthly purchases are geared towards German bonds, 20% towards French bonds, 17% towards Italian bonds, and 13% towards Spanish bonds (ECB, 2017).

ply in private markets.[19] Hence, the local supply channel does not necessarily focus on maturity-dependent risk, but deals with instrument-specific, idiosyncratic risk premia that reflect supply and demand imbalances for a particular security. This can be further illustrated by decomposing the long-term bond yield $y_t^{(n)}$ into

$$\begin{aligned} y_t^{(n)} &= y_{rn,t}^{(n)} + tp_t^{(n)} \\ &= y_{rn,t}^{(n)} + tp_{risk,t}^{(n)} + tp_{instr,t}^{(n)}. \end{aligned} \tag{5.7}$$

In general, the n-period yield of a default-free government bond consists of the average future short-term rate, $y_{rn,t}^{(n)}$, and the term premium, $tp_t^{(n)}$. As will be discussed in section 5.2.1 in more detail, the evolution of $y_{rn,t}^{(n)}$ is associated with the *signaling channel* of LSAPs. The term premium, however, can be further specified by decomposing it into a maturity-specific term premium, $tp_{risk,t}^{(n)}$, and an instrument-specific term premium, $tp_{instr,t}^{(n)}$. The first component is related to interest rate risk and captures the *duration risk channel*. The latter, by measuring supply and demand imbalances for a particular security, reflects the *local supply channel* of LSAPs.

For example, if some investors have a special demand for long-term, essentially default-free government bonds, then these investors view government bonds as imperfect substitutes for alternative bonds with similar duration. Ceteris paribus, government bond purchase programs thus create a *shortage of safe bonds* in private markets. As a consequence, the prices of safe bonds soar and the risk spread to defaultable bonds moves *in excess* of the risk premium implied by the standard capital asset pricing model. This pattern, which Krishnamurthy and Vissing-Jorgensen (2011) coined the *safety channel* of LSAPs, is illustrated in Figure 5.7.

The straight dashed line shows the bond price according to the consumption based asset pricing model (see section 3.2 for a detailed explanation of the pricing kernel in the C-CAPM). It depicts an inverse relation between the bond price and the underlying default probability. The distance between the C-CAPM-line and the lower curve reflects the safety premium that originates from clientele's demand for bonds with marginal default risk. Following the empirical finding of Longstaff et al. (2005), the cutoff for safe bonds is assumed to lie at the investment-grade threshold (BBB rating in the S&P classification, meaning at least Credit Quality Step 3 in the Eurosystem's harmonised ra-

[19]Note however that the increase in short-term yields should be subdued if at the zero lower bound, short-term bonds and money became close substitutes. For a more detailed discussion on this point, see section 8.4.

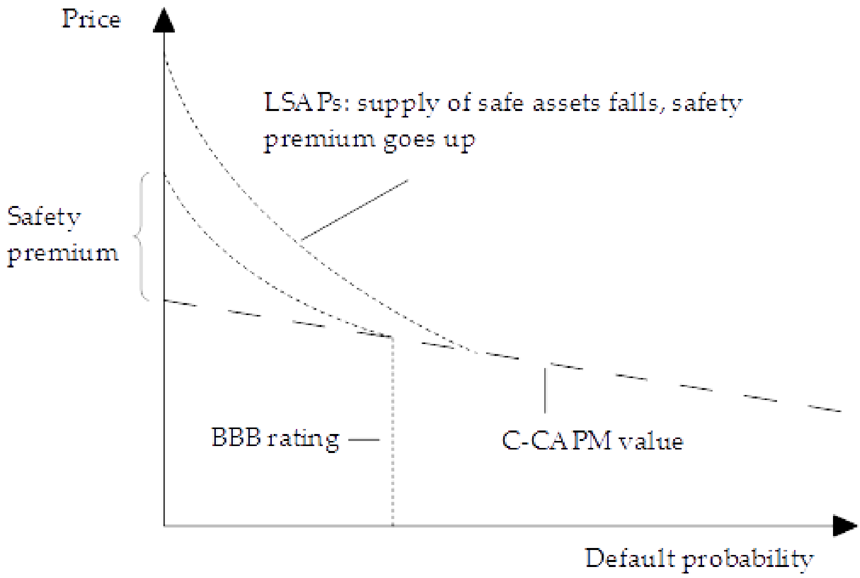

Figure 5.7.: Price impact of the safety channel

ting scale (Committee of European Banking Supervisors, 2017)).[20] When a central bank engages in a LSAP program, it reduces the supply of long-term safe assets remaining in the market. Therefore, private investors face an aggregate shortage of safe assets and their willingness to pay for a unit of safety increases. As a result, the safety premium on government bonds shifts upwards. The latter is depicted by the upper dotted curve in Figure 5.7.

In principle, such local supply effects can occur for a variety of reasons. For instance, if investors have strong preferences for specific maturities (e.g. pension funds with a specific demand for long-term bonds), then LSAPs lower the yields on that part of the yield curve above and beyond the effect implied by standard asset pricing models. In such an event, an asset purchase program that shortens the supply of bonds with specific maturities cause the yield curve to exhibit a hump-shaped form as depicted in Figure 4.9. Once again, this should clarify the distinction between the duration channel and the local supply channel. The duration channel operates independently of preferred-habitat investors, as the total quantity of duration risk is a common risk factor even if asset prices are determined solely by arbitrageurs. In other words, the finding that asset prices

[20]Notably, the investment-grade threshold also represents the minimum credit quality for assets eligible as collateral in the ECB's credit operations. The ECB has lowered this credit threshold from A- to BBB- in October 2008 (ECB, 2008). With the exception of ABS, the investment-grade threshold also applies to the securities acquired under the corporate sector purchase program (ECB, 2015a).

depend on supply shocks does not suffice to prove the preferred-habitat hypothesis. A better test for the preferred-habitat hypothesis is whether *persistent* local supply effects exist. Economic theory would predict that a persistent local supply effect can exist only within distressed financial markets, as these states are typically characterized by a low risk-bearing capacity of arbitrageurs. The following sections try to assess whether this hypothesis is valid by reviewing the empirical evidence in the US, the UK, and the euro area.

5.1.2.1. Empirical Evidence for the US

Using US-Treasury data from 1926-2008, Krishnamurthy and Vissing-Jorgensen (2012) show that a one-standard-deviation reduction in Treasury supply from its historical mean lowers the yields on long-term Treasuries relative to Baa-corporate bonds by 77 basis points. In a subsequent study, the authors then assess to what extent the safety channel contributed to the yield effect within the Fed's first and second LSAP program, using both an event study and a time-series approach (Krishnamurthy and Vissing-Jorgensen, 2011).

Event Studies In the event study approach, Krishnamurthy and Vissing-Jorgensen (2011) assess the impact of LSAP1 and LSAP2 around the following event dates:[21]

Program	Date	Event Description
LSAP1	Nov. 25, 2008	FOMC statement: first announcement of the intention to buy $500 billion agency MBS and $100 billion of agency debt (FOMC, 2008).
	Dec. 01, 2008	Bernanke speech: indication that the Fed could buy Treasuries and provide a liquidity backstop for certain financial markets (Bernanke, 2008).
	Dec. 16, 2008	FOMC statement: decision to lower the target range for the federal funds rate to 0-0.25 percent. In addition, announcement that the Fed stands ready to expand ongoing asset purchases, considers purchasing longer-term Treasuries, and implements the Term Asset-Backed Securities Loan Facility to facilitate the extension of credit to households and small businesses (FOMC, 2008).

[21] As already argued elsewhere, in the event study literature, there is an inherent trade-off with respect to the window size. Setting it too short involves the risk of missing lagged asset price reactions; setting it too long can distort the results by measuring asset price effects that are unrelated to the policy event. Krishnamurthy and Vissing-Jorgensen (2011) choose a two-day window size. One reason for this relatively long window is that they consider low-liquidity assets, such as agency MBS. Another reason is motivated by the idea that, at least during LSAP1, financial markets were severely impaired, which should cause a delay in the yield response that is larger than in normal times.

	Jan. 28, 2009	FOMC statement: 75 basis point decrease in the discount rate plus renewed emphasis that the Fed stands ready to further expand its balance sheet (FOMC, 2009a).
	Mar, 18, 2009	FOMC statement: increase in the size of LSAP1 to a total of $1.25 trillion for agency MBS, $200 billion for agency debt, and decision to include $300 billion of longer-term Treasuries (FOMC, 2009b).
LSAP2	Aug. 10, 2010	FOMC statement: first announcement indicating that LSAP2 will focus on longer-term Treasuries instead of agency bonds and agency MBS as in LSAP1. In addition, commitment that the Fed maintains its balance sheet size by reinvesting the principal payments from agency debt and agency MBS into Treasuries (FOMC, 2010a).
	Sep. 21, 2010	FOMC statement: announcement that Fed is "prepared to provide *additional* accommodation if needed to support economic recovery" (FOMC, 2010b, emphasis added).

Table 5.6.: Identified policy events for LSAP1 and LSAP2.

Concerning LSAP2, especially the September announcement was interpreted by many market participants as an indication of further large-scale purchases of long-term government bonds. For example, a survey on private sector economists conducted by the Wall Street Journal in early October 2010 found that the Fed was expected to buy $750 billion in Treasury bonds (Hilsenrath and Cheng, 2010). Those expectations were then largely met when the Fed, on November 3, 2010, decided to purchase an additional amount of $600 billion in longer-term Treasury bonds.[22] Table 5.7 summarizes the overall yield changes of Treasury bonds, GSE agency bonds, and agency MBS for both programs.

Since Treasury and agency debt bonds are both ultimately backed by taxpayer money, they carry essentially no default risk (i.e. they are equally safe). Therefore, any yield differentials between Treasuries and agency bonds that have the same maturity must be due to the securities' different liquidity characteristics. The reason is that LSAP programs financed by reserves reduce the liquidity premium that Treasuries command over agency bonds. That is, the liquidity effect *rises* the yield on Treasury bonds relative to agency bonds, which runs counter to the yield effect of the safety channel. As a consequence, agency bonds experience the strongest yield effect in table 5.7 (in the case of 10-year agency bonds, 200 basis points for LSAP1, and 29 basis points for LSAP2). In ad-

[22]The November announcement is thus excluded from the event study, since its results were already expected by market participants, i.e. it did not entail any 'news' about the monetary policy stance.

		Treasury yields (constant maturity)			Agency debt yields (Fannie Mae)			Agency MBS yields	
	Date	30-yr	10-yr	5-yr	30-yr	10-yr	5-yr	30-yr	15-yr
LSAP1	Nov. 25, 2008	-24	-36	-23	-57	-76	-57	-72	-88
	Dec. 1, 2008	-27	-25	-28	-52	-67	-50	-14	12
	Dec. 16, 2008	-32	-33	-15	-37	-39	-26	-26	-16
	Jan. 28, 2009	31	28	28	33	28	27	31	20
	Mar. 18, 2009	-21	-41	-36	-31	-45	-44	-27	-16
	Sum of dates	-73*	-107**	-74	-144**	-200***	-150***	-107*	-88
LSAP2	Aug. 10, 2010	-8	-14	-10	-8	-13	-9	-4	-8
	Sep. 21, 2010	-13	-16	-10	-14	-16	-10	-4	-5
	Sum of dates	-21***	-30***	-20***	-22***	-29***	-20***	-8	-13**

Table 5.7.: Two-day yield changes around LSAP1 and LSAP2 event dates ◇ Asterisks denote statistical significance at the ***1 percent, **5 percent, and *10 percent level ◇ *Source:* Krishnamurthy and Vissing-Jorgensen (2011)

dition, Krishnamurthy and Vissing-Jorgensen (2011) estimate that the *signaling channel* had a maximum impact of -40 basis points for LSAP1 and -11 basis points for LSAP2 (for a further explanation on the signaling channel, see section 5.2.1).[23]

Furthermore, compelling evidence for the *duration risk channel* is found neither for LSAP1, nor for LSAP2. Hence, for the first program, the *safety channel* accounts for a reduction in 10-year agency yields of about $200-40=160$ basis points, and $107-40=67$ basis points for 10-year Treasuries.

Interestingly, for reasons discussed below, the effects of LSAP2 on yields are consistently below the effects of LSAP1. Despite the lower overall effectiveness of the second program, however, Table 5.7 reveals that the safety channel was also among the primary channels within LSAP2. With a signaling effect of 11 basis points and only minor evidence for the liquidity channel (as there is essentially no difference between Treasury and agency bonds of the same maturity), the safety premium accounts for a decline in 10-year agency bonds of about $29-11=18$ basis points, and $30-11=19$ basis points for 10-year Treasury, respectively.

Time-Series Regressions As noted above, especially in times of heightened uncertainty in financial markets, the forecast precision of market participants about the outcomes of LSAP announcements might be severely impeded. Nevertheless, the traditional

[23] The estimates are based on the evaluation of federal funds future contracts. Unfortunately, data on federal funds future contracts exist only up to two years. To estimate the signaling effect for longer horizons, Krishnamurthy and Vissing-Jorgensen (2011) extrapolate the two year effect, and they found a maximum impact for the 10 year horizon. This constitutes an upper bound on the signaling effect, since market expectations for longer horizons should anticipate a normalization of current short-term rates.

event study of Krishnamurthy and Vissing-Jorgensen (2011) rests upon the assumption that market participants are fully capable to interpret central bank announcements – implying that actual asset purchases are rendered irrelevant for determining the prices and yields of financial assets. Given these caveats, the quantitative results from the traditional event study of Krishnamurthy and Vissing-Jorgensen (2011) should be treated with caution.

As a robustness check, Krishnamurthy and Vissing-Jorgensen (2011) therefore compare their event study estimates with estimates from a time-series regression. Based on the intuition presented in Figure 5.7, they regress the Baa-Treasury spread on a maturity-based measure of the Treasury supply. The measure for the Treasury supply is denoted by LONG-SUPPLY and includes all Treasury bonds with a remaining maturity of 2 years or more.[24] The regression equation, estimated using annual data from 1949 to 2008, is thus given by

$$\text{Yield Spread}_t = \text{controls}_t + \beta\,(\text{LONG-SUPPLY}_t/\text{GDP}_t) + \epsilon_t. \qquad \langle 5.8\rangle$$

The yield spread between Treasury bonds with marginal default probability and Baa-rated corporate bonds includes both a default risk premium and a safety premium. While the first is driven by the standard arguments for idiosyncratic risk compensation, the latter is due to the demand of preferred-habitat investors for particularly safe assets. To disentangle the default risk premium from the safety premium, the regression thus includes as default control variables a measure for stock market volatility (the standard deviation of weekly stock returns over the preceding year) and, as a proxy for the yield curve, the difference between the 10-year Treasury yield and the 3-month money market yield.[25]

The estimated β coefficient equals -0.83, indicating that as expected a decrease in the supply of safe assets results in an increase in the Baa-Treasury spread.[26] In terms of 10-year equivalents, Krishnamurthy and Vissing-Jorgensen (2011) document that LSAP1 has removed \$169 billion of Treasury bonds, \$72 billion of agency bonds, and \$573

[24] For the regression to be comparable across different purchase programs, the measure LONG-SUPPLY is computed in "10-year equivalents". The concept of 10-year equivalents for evaluating LSAP was first introduced by Gagnon et al. (2011a). For further details on the calculation method, see the explanations given in Krishnamurthy and Vissing-Jorgensen (2011).

[25] To address a potential endogeneity problem, LONG-SUPPLY in equation ⟨5.8⟩ is instrumented by the total supply of government debt. The instrument's relevance is confirmed by a simple regression showing a highly significant relation between total debt and the measure of long-term debt (see Krishnamurthy and Vissing-Jorgensen, 2012, for details on the instrumental variable estimation).

[26] The corresponding t-value equals -5.83.

of agency MBS. Since, however, agency MBS carry prepayment risk, only Treasuries and agency bonds are counted as safe bonds. Given the information that the pre-LSAP1 supply of 10-year equivalent safe bonds stood at $1,983 billion and GDP at $14,292 billion, LSAP1 has decreased the LONG-SUPPLY/GDP measure to 1,742/14,292. It thus follows that LSAP1 through the safety channel led to a -0.11 basis points decrease in the Treasury-Baa spread.

LSAP2 was implemented under different conditions. Firstly, once the Fed had terminated LSAP1, expansive fiscal measures led to a significant re-rise in the amount of privately held Treasury debt (see the upper panel in Figure 5.1). Since, in addition, the average duration of outstanding Treasury bonds increased (see also the lower panel in Figure 5.1), the supply measure for 10-year equivalent safe bonds at the beginning of LSAP2 stood at $4,181 billion. Secondly, however, during LSAP2 the Fed removed more safe bonds from the market than with LSAP1 ($511 vs. $241 billion). According to this metric, the LONG-SUPPLY/GDP measure for LSAP2 thus equals 3,670/15,230, implying that the Treasury-Baa spread fell by -20 basis points.

Comparing the event study and time-series results for the safety channel, it is striking to note that for LSAP1 the regression estimates are significantly below the event study estimates (11 vs. 67 basis points), whereas for LSAP2 they are almost identical (20 vs. 19 basis points). A possible explanation could be that the regression model is estimated using annual pre-crisis data (1949 to 2008), i.e. for an average demand for safety, whereas LSAP1 was conducted at times when the demand for safety was extraordinarily high (2008-2009). In contrast, the LSAP2 was implemented under more normalized market conditions (2010, see also Figure 6.1). Therefore, the time-series estimates for LSAP1 are likely to understate the program's true effectiveness, while the estimates for LSAP2 seem to be more appropriate to measure the safety channel.

Panel Regressions Beyond the structural problems illustrated above, time-series regressions on the yield effects of LSAPs suffer from various other problems. Firstly, they are likely to suffer from endogeneity problems that are typical for any estimation of the relation between prices and quantities. Secondly, most studies in this field regress constant-maturity yields on aggregate data of Treasury debt. By relying on aggregate data, however, most of these studies ignore that supply effects can vary across different types of securities. Finally, time-series regressions based on the aggregate level of outstanding Treasury debt have difficulties separating the local supply channel from alternative channels through which Treasury purchases may affect yields. To address those caveats, D'Amico and King (2013) propose a panel-regression using security-level data instead of aggregate data and constant-maturity yields. This more granular approach allows them to analyze local supply effects conditional on security-specific characteristics such as maturity or liquidity. The general regression specification is given by

$$R_i^{(n)} = \gamma_0 q_{i,0} + \sum_{j=1}^{J} \gamma_j q_{i,j} + \phi(n) + \epsilon_i \tag{5.9}$$

where R_i denotes the gross return on any individual Treasury i with a remaining maturity of n. The variable $q_{i,0}$ represents the quantity of security i purchased under the LSAP program, while $q_{i,j}$ represents its nearby substitutes. The parameter γ_0 thus measures the own-price elasticity of Treasury i, while the parameters $\gamma_j, \ldots, \gamma_J$ reflect the cross-price elasticities with respect to potential substitutes. Furthermore, $\phi(n)$ is a smooth function of n and captures both the signaling channel as well as the duration channel of LSAP. To address potential endogeneity problems, D'Amico and King (2013) run a cross section two-stage least square estimation. In the first state, they instrument the level of purchases using pre-LSAP information. In doing so, they account for the possibility that the Fed might have preferred to purchase undervalued securities during the LSAP program, which would have caused biased estimation results. In the second-stage regression, they thus use the instrumented purchases from the first stage as the exogenous variables and the cumulative change in a security i's gross return as the endogenous variable. The second-stage regression is thus given by

$$R_i^{(n)} = \gamma_0 \hat{q}_{i,0} + \gamma_1 \hat{q}_{i,1} + \phi_0 + \phi_1 n_i + \phi_2 n_i^2 + \epsilon_i \tag{5.10}$$

where hats indicate instrumented variables and n is the remaining maturity as of March 17, 2009. Furthermore, only the quantity of near substitutes, $\hat{q}_{i,1}$, i.e. Treasuries having a remaining maturity within two years of the security i's maturity, are included.

Concerning the \$300 billion of Treasury purchases under LSAP1, D'Amico and King (2013) estimate that the local supply effect had an average effect on Treasury yields of about -30 basis points, with its main impact at intermediate maturities (as much as 50 basis points for bonds with remaining maturities between 10-15 years). This dispersion of yields across maturities is relatively large compared to historical regularities. Regarding the transmission process of LSAP1, the observation that intermediate yields declined more than long-term yields supports the view that the local supply channel was more important than the duration channel.

This conjecture may be confirmed by the results of Meaning and Zhu (2011), who adopt the methodology of D'Amico and King (2013) to both the Fed's second round of QE and to its first maturity extension program of 2011-2012. For LSAP2 (MEP1), they find that average yields due to the local supply channel decreased by about 21 (22) basis points. Given that the Fed purchased double the amount of Treasuries under LSAP2, this underscores the conjecture that LSAP1 was relatively more efficient than LSAP2.[27] Once more, this empirical result supports the theoretical predictions of the preferred-habitat theory: since LSAP2 and MEP1 were conducted during times of improved risk bearing capacity by arbitrageurs (less market segmentation), its yield impact must have been lower compared to LSAP1. Finally, it should be noticed that although the quantitative estimates on the local supply channel vary to some extent conditional on the econometric methodology, all the qualitative evidence seems to be largely consistent with the insights from economic theory.

5.1.2.2. Empirical Evidence for the UK

Concerning the BoE's first asset purchase program (APF1), probably the clearest evidence for the *local supply channel* is documented by Joyce et al. (2011a). Following equation ⟨5.7⟩, they deconstruct the term premium of a n-period government bond into

$$tp(gilt)_t^{(n)} = tp(gilt)_{risk,t}^{(n)} + tp(gilt)_{instr,t}^{(n)}, \qquad \langle 5.11 \rangle$$

where the first component, $tp(gilt)_{risk,t}^{(n)}$, captures the *duration risk* of gilts, while $tp(gilt)_{instr,t}^{(n)}$ captures instrument specific supply and demand imbalances (the *local supply channel*).[28] Additionally, to isolate the *signaling channel* of LSAP, they use interest rate data on overnight index swaps (OIS) based on the average overnight rate for unsecured transactions in the Sterling market (SONIA).[29] Under the assumption that OIS rates, as

[27] In fact, the $600 billion in Treasury purchases may understate the real size of LSAP2, as the Fed also reinvested the principal payments it received from previous programs. Taking those payments into account, the Fed purchased approximately $750 billion in long-term Treasury debt during the course of LSAP2.

[28] In principle, the instrument-specific component of the term premium also involves the liquidity premium. But Joyce et al. (2011a) find no material relationship between APF1 and the liquidity channel.

[29] In an OIS contract, swap partners exchange fixed interest rate payments for variable rate payments over the life of the contract. The variable rate is usually derived from the interbank overnight rate of the OIS currency. Thus, OIS yields reflect market expectations about the future course of the short-term interest rate. At maturity, the swap is settled by computing the difference between fixed rate payments and the average of the variable rate payments on the notional swap principal. Since swap partners only exchange net interest differentials at maturity but no principal, OIS contracts carry neither default nor liquidity risk.

derivatives contracts, are not affected by supply constraints in the government bond market, i.e. $tp(OIS)^{(n)}_{instr,t} = 0$, the yield on a maturity-matched n-period OIS contract is given by

$$y(OIS)^{(n)}_t = y^{(n)}_{rn,t} + tp(OIS)^{(n)}_{risk,t} \qquad \langle 5.12 \rangle$$

where the average future short-term rate, $y^{(n)}_{rn,t}$, akin to equation ⟨5.7⟩, captures the *signaling channel* of LSAP. This includes that the term premium component of the gilt yield reflecting duration risk is the same as in the maturity-matched OIS-rate, i.e. $tp(gilt)^{(n)}_{risk,t} = tp(OIS)^{(n)}_{risk,t}$, such that subtracting equation ⟨5.12⟩ from ⟨5.7⟩ yields

$$y(gilt)^{(n)}_t - y(OIS)^{(n)}_t = tp(gilt)^{(n)}_{instr,t}. \qquad \langle 5.13 \rangle$$

The gilt-OIS spread thus represents a proxy for the *local supply channel* associated with instrument-specific supply and demand imbalances in the gilts market.

Figure 5.8 depicts the cumulative one-day changes in Gilt-OIS spreads for the four significant event dates listed in Table 5.2 (Mar. 05, May 07, Aug. 06, and Nov. 05, 2010). What seems to be remarkable here is the relatively strong and persistent decline in bond yields with residual maturities between 5 and 25 years (highlighted by the gray area in Figure 5.8). In fact, this effect has prevailed even after the the MPC statement of Aug. 06, 2010, where the maturity range for gilt purchases was extended to a minimum residual maturity of 3 years. The resulting hump-shaped yield curve suggests limited arbitrage and market segmentation in this maturity range, which in fact resembles pretty well the stylized local supply channel depicted in Figure 4.9. At the same time, however, the yield curve on Nov. 06, 2010 seems to suggest that over the course of APF1, arbitrage in the gilt has gradually recovered over time.[30] Irrespective of this gradual recovery, Joyce et al. (2011a) estimate that the local supply effect of APF1 has reduced 10-year gilt yields by about 55 basis points.

Compared to other studies, the estimates by Joyce et al. (2011a) constitute the upper bound. The cross-sectional study of Meaning and Zhu (2011) for example finds an average downward effect on 10-year gilt yields of about 27 basis points, while McLaren et al. (2014) estimate an intermediate effect of 48 basis points.[31] Given this high disper-

[30] A supporting factor for the pick-up in arbitrage activity could be the BoE's gilt lending program. Initiated in August 2009 in cooperation with the UK Debt Management Office (DMO), this program allowed private market participants to obtain gilts from the APF's portfolio in return for a fee and the placement of alternative gilts as collateral. Hence, the overall level of the APF's gilt holdings remained unaffected. It seems that the lending facility relieved frictions in the gilt market that arose because the APF's gilt purchases had led to a shortage of certain gilts in the the open market (Bank of England, 2010).

[31] Using changes in the auction maturity sectors in BoE's subsequent rounds of asset purchases, McLaren

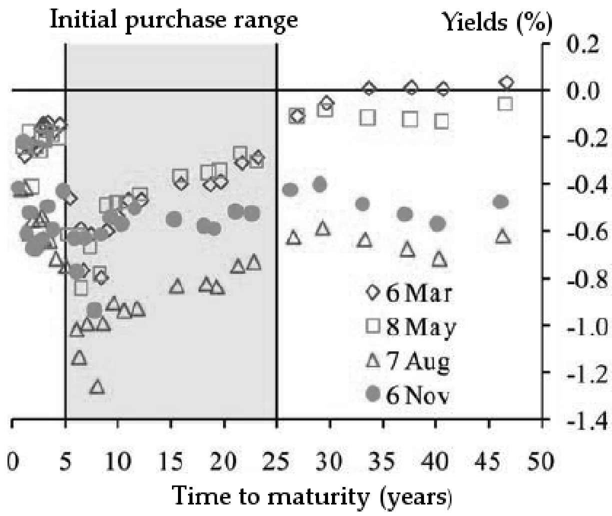

Figure 5.8.: Cumulative changes in Gilt-OIS spreads since February 10, 2009.
◇ *Source*: Joyce et al. (2011a, p. 132).

sion of estimates, it is hard to come up with conclusive evidence about the relative efficiency of the various purchase programs. However, the fact that the BoE, during APF1, acquired approximately 32% of the free float of gilts, while the treasury purchases of LSAP1 and LSAP2 accounted only for about 5%, respectively 7% of total privately held government debt, suggests that APF1 was less effective in lowering yields than the two Fed programs. This relative effectiveness of the different programs with respect to the local supply effect is illustrated in Figure 5.9.

5.1.2.3. Empirical Evidence for the Euro Area

Arguably, the main impacts of QE in the euro area came from *duration* and *credit risk* effects, while the *local supply channel* played only a marginal role (see also section 5.1.1.3). To further test this conjecture, the timing of events in the ECB press conference on January 22, 2015, offers an interesting case study.[32] At 14:40 ECT, Mario Draghi announced that the existing private sector asset purchase program (including ABSPP and CBPP2) would be expanded by a large-scale asset purchase program for public sector bonds (PSPP). And while the combined average monthly purchases were specified at €60 bil-

et al. (2014) argue that the local supply channel can explain about one half of the total impact of the BoE's APF on gilt yields. Moreover, their result seems to suggest that the impact of the local supply effect did not decrease during the later rounds of recent LSAPs.

[32]Initially, this exercise has been proposed by Altavilla et al. (2015).

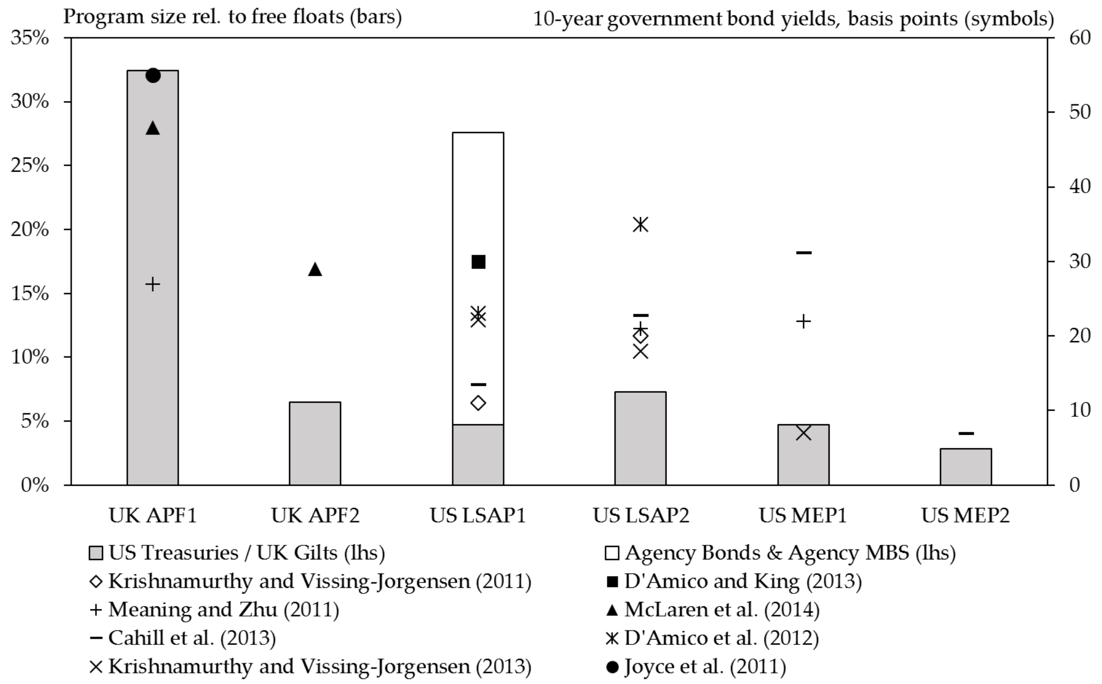

Figure 5.9.: Effectiveness of local supply channel across US and UK ◇ Program sizes are calculated as the purchase volume of sovereign bonds relative to the free float of sovereigns at the beginning of each program. ◇ *Source:* Cited studies, Federal Reserve, Bank of England, Department of the Treasury (2016), Table OFS-2, United Kingdom Debt Management Office (2016).

lion, the program was intended to run until September 2016.[33] Under this premise, markets should have inferred from the announcement that the ECB was going to buy public sector bonds for about €893 billion (i.e. €47 billion per month).[34] Given that previous market expectations hovered around €500 to €600 billion (Kennedy and Speciale, 2014; Reuters, 2015), the January PSPP announcement clearly came as a positive *size shock* to market participants.

A similar observation can be made with respect to the PSPP's expected maturity range. Here, survey data suggests that prior to the announcement market participants

[33]To be precise, the length and therefore also ultimate purchase volume of the program was made conditional on the evolution of the euro area inflation rate. At the outset, I assume that the program was expected to be terminated in September 2016.

[34]With respect to the breakdown of the monthly purchases between public and private sector assets, Mario Draghi mentioned that "What you could look at is basically the past behavior [of purchases under CBPP3 and ABSPP] as inference for the future behavior of our purchases" (see ECB, 2015d). Since the average monthly purchases under ABSPP and CBPP3 equaled about €13 billion, markets should have perceived that the ECB would buy public sector assets for about $(60 - 13) \times 19 = 893$ billion.

expected the ECB to buy euro area government bonds with residual maturities of 2-10 years.[35] That means when Mario Draghi, during the press conference on January 22, 2015, announced at 15:10 ECT that the ECB was going to buy bonds with residual maturities of 2-30 years, this represented a positive *maturity shock* for bond market investors. By using high-frequency data on German sovereign yields, Figure 5.10 tries to disentangle these two effects of the PSPP announcement.

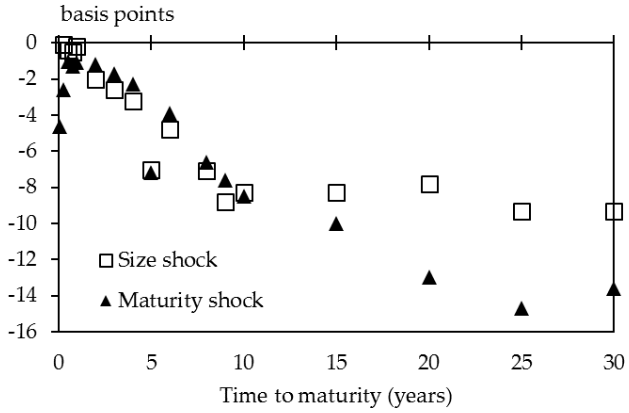

Figure 5.10.: High-frequency response of German sovereign yields to PSPP announcement (January 22, 2015). ⋄ The white squares (black triangles) denote the yield response to the size (maturity) shock. ⋄ *Source:* Datastream.

Interestingly, the high-frequency reaction of German sovereign yields, in contrast to the reaction of British gilt yields depicted in Figure 5.8, is generally inconsistent with the predictions from the local supply channel. Firstly, according to the narrow predictions of the local supply channel, bond yields above 10 years should *not* have reacted to the size shock of the policy announcement, as investors had no reason to believe that the ECB would buy bonds with remaining maturities above that threshold. Instead, however, as shown by the white squares in Figure 5.10, yields above 10 years fell broadly in line with those of 10 year maturity bonds. Secondly, the maturity shock at 15:10 ECT should have led to an *increase* in yields below 10 years, because it meant that less bonds would be purchased in this maturity range. Instead, what can be observed by the black triangles in Figure 5.10 is that yields below 10 years either did not move significantly, or

[35]In particular, Altavilla et al. (2015, p. 33) document a survey conducted among money market participants in December 2014, which gives the following results for the expected maturity buckets of the PSPP: 2-10 years for J.P. Morgen; 5-10 years for Goldman Sachs, and 3-10 years for Nomura.

even slightly decreased relative to the white squares.[36] In fact, the entire German yield curve experienced a downward shift in response to the PSPP announcement – and this effect increased with time to maturity – which is precisely the reaction predicted by the duration channel (see Figure 4.8). Hence, this supports the view that the local supply channel did not play a dominant part for German sovereign bonds. At first, this might seem surprising, given that German sovereign bonds are highly safe and thus relatively scarce compared to other euro area bonds. Yet if the local supply channel is negligible for German bonds, one can fairly assume that is close to irrelevant for QE as a whole.

5.1.2.4. Policy Implications

The empirical evidence for the local supply channel is clearly consistent with the preferred-habitat theory presented above. The latter states that if arbitrage is limited and investors have an instrument-specific demand for a given asset, then central bank purchases of that asset will cause a *local* price effect.[37] But although limits to arbitrage *increase* this local price effect, they also effectively *decrease* potential spillover effects to alternative assets.[38] Under such conditions, monetary policy should thus not only buy assets in distressed markets, but include a wide range of securities in order to ease *overall* lending rates. Moreover, the predictions of the local supply channel might be relevant for the unwinding of LSAPs. Given its counter-cyclical effectiveness, selling-off assets should have a relatively lower impact on yields when market conditions normalize.

5.1.3. Reserve Channel

The seminal model of Vayanos-Vila presented in section 5.1 contains neither a banking sector nor does it include any special role for reserves.[39] Instead, central bank asset purchases are conceived as exogenous variations in the supply of long-term assets. Yet when a central bank conducts LSAPs in practice, it pays for the acquired assets by issuing reserves – and this reserve expansion *per se* can be an integral part in the transmission process of LSAPs.

[36] Also inconsistent with the local supply channel is the relatively large drop in yields of bonds with remaining maturities below 2 years, as these bonds were not eligible under the PSPP.
[37] The same holds true of course for investor-specific maturity demands.
[38] Consistently, this channel had a significant impact on early rounds of QE – especially in the US and the UK – but played only a miniscule part in the euro area.
[39] In this respect, the Vayanos-Vila model resembles Woodford's cashless economy (see Woodford, 2003, ch. 3.2).

The Model A model that accounts for such a reserve-induced liquidity effect on private sector balance sheets is presented by Christensen and Krogstrup (2016a). The authors built a partial equilibrium model that incorporates a central bank and splits the private sector into non-banks and banks. Thereby, the authors shed light on the role of reserves in the transmission process of LSAPs to bond yields. Critically, the model assumes that only banks have access to reserve accounts with the central bank, which gives rise to two distinct portfolio balance effects: at first, there is a classical *supply-induced portfolio balance effect* resulting from the reduced supply of the purchased assets to the private sector.[40] The second, the so-called *reserve-induced portfolio balance effect*, runs through banks' reactions to the reserve expansion but is independent of the assets purchased.

Bond Market Another critical assumption of the model is that long-term bonds and reserves are imperfect substitutes, while reserves and deposits are regarded are perfectly substitutable. With a notional value of one, those assumptions generate a term premium for long-term bonds given by

$$tp = 1 - P_L. \tag{5.14}$$

In the model, this term premium arises because selling long-term bonds prior to maturity involves uncertainty about the achievable price. As this is not the case for deposits which can be readily transferred into money whenever needed, investors demand a term premium for holding long-term bonds.[41]

Central Bank To mirror current LSAPs, it is assumed that the central bank buys (and holds) only long-term bonds (B_L^{CB}).[42] The balance sheet identity of the central bank is thus given by

$$P_L B_L^{CB} = E^{CB} + R. \tag{5.15}$$

[40] This can be either the duration or local-supply channel as presented in the previous sections.

[41] Besides this term premium, long-term bonds carry neither a liquidity premium nor a credit premium. If long-term bonds carried a liquidity premium, as they do in the model of Krishnamurthy and Vissing-Jorgensen (2011), for instance, increasing the supply of reserves would reduce the liquidity premium on long-term bonds. Allowing for such a liquidity premium would thus reduce the term premium in equation ⟨5.14⟩ accordingly.

[42] This reduced form model is meant to highlight the reserve-induced portfolio channel on long-term bond yields. A more realistic version of the model, in which the central bank holds also short-term securities, is laid out in the Appendix B.4. As will be shown, however, the reserve-induced portfolio channel might also work if LSAPs comprise only short-term bonds.

where the central bank's liabilities consist of equity (E^{CB}) and reserves (R). As the central bank finances its bond purchases by issuing reserves, it follows that $\mathsf{d}R = P_L \mathsf{d}B_L^{CB}$. Therefore, the change in the central bank's equity position is given by

$$\mathsf{d}E^{CB} = \mathsf{d}P_L B_L^{CB} + P_L \mathsf{d}B_L^{CB} - \mathsf{d}R \qquad \langle 5.16 \rangle$$

meaning that changes in E^{CB} are only driven by changes in the bond price:

$$\mathsf{d}E^{CB} = \mathsf{d}P_L B_L^{CB}. \qquad \langle 5.17 \rangle$$

This implies that LSAPs expose the central bank to interest rate risk.[43]

Non-Banks By assumption, the balance sheet size of the non-bank sector (pension funds, money market mutual funds, hedge funds etc.) is predetermined by a given amount of equity, E^{NB}; and while non-banks do not issue any kind of debt, they hold a combination of bonds (B_L^{NB}) and deposits (D^{NB}) as assets. Furthermore, deposits (and reserves) pay no interest in the model, which can be justified on the ground that LSAPs are typically conducted when short-term rates are zero. Thus, the balance sheet identity of the aggregate non-bank sector equals

$$P_L B_L^{NB} + D^{NB} = E^{NB}. \qquad \langle 5.18 \rangle$$

Consequently, changes in non-bank equity are the residual of the flow budget constraint

$$\mathsf{d}E^{NB} = \mathsf{d}P_L B_L^{NB} + P_L \mathsf{d}B_L^{NB} + \mathsf{d}D^{NB}. \qquad \langle 5.19 \rangle$$

Note that non-banks do not hold reserves directly. Instead, they hold deposits with the banking sector that represent readily available (indirect) claims on central bank reserves. Another important assumption of this model is that non-banks cannot issue neither new debt nor equity, which implies that the sole possibility for a non-bank to get new deposits is to sell bonds. Therefore,

$$\mathsf{d}D^{NB} = -P_L \mathsf{d}B_L^{NB}, \qquad \langle 5.20 \rangle$$

[43] Indeed, interest rate risk can be an important risk factor for central banks. The Bundesbank, for example, in 2016 increased its risk provisioning by €1.75 billion. Besides exchange rate and credit risk, this was mainly due to higher interest rate risk associated with its large-scale asset purchases (Weidmann, 2017).

and in analogy to equation ⟨5.17⟩ for the central bank, changes in the equity position of non-banks are solely due to changes in the bond price,

$$\mathrm{d}E^{NB} = \mathrm{d}P_L B_L^{NB}. \tag{5.21}$$

Importantly, non-banks demand a certain portfolio composition between bonds and deposits, which give rise to a portfolio balance effect. The non-banks bond demand is thus a function of its price and the equity position of non-banks. With standard preferences, this demand function $f^{NB}(P_L, E^{NB})$ is inversely related to the bond price

$$\frac{\partial f^{NB}(P_L, E^{NB})}{\partial P_L} < 0 \tag{5.22}$$

while it is further assumed that non-banks do not immediately adjust their bond holdings in response to equity value changes, such that

$$\frac{\partial f^{NB}(P_L, E^{NB})}{\partial E^{NB}} = 0. \tag{5.23}$$

The latter condition ensures that non-banks bond demand is only determined by variations in the bond price, i.e.

$$\mathrm{d}B_L^{NB} = \frac{\partial f^{NB}(P_L, E^{NB})}{\partial P_L}\mathrm{d}P_L, \tag{5.24}$$

which can be substituted into equation ⟨5.20⟩ to yield

$$\mathrm{d}D^{NB} = -P_L\frac{\partial f^{NB}(P_L, E^{NB})}{\partial P_L}\mathrm{d}P_L. \tag{5.25}$$

This equation establishes a positive relation between changes in bond prices and non-banks demand for deposits. Given standard preferences for bonds, non-banks will sell bonds when their prices rise and hold the proceeds in their deposit accounts.

Banks At first, notice once again that the model is built to focus on the bond market effects of LSAPs. Therefore, it is assumed that banks do not immediately adjust their credit portfolios to changes in funding conditions, which is the reason why loans are normalized to zero in the model. Hence, the balance sheet of the aggregate banking sector can be written as

$$R + P_L B_L^B = E^B + D^B \tag{5.26}$$

where the funding of banks is simply[44]

$$F^B = E^B + D^B. \qquad \langle 5.27 \rangle$$

A related assumption is that in this model 'loans *don't* create deposits', which implies that the stock of deposits is ultimately determined by the behavior of non-banks. This assumption is not meant to discard the modern view whereupon deposits are endogenously supplied by the credit creation of banks (see McLeay et al., 2014). Instead, it is meant to highlight the implications of the reserve-induced portfolio balance effect with respect to long-term bond yields. As a result, banks' reserves exogenously increase with their deposits and decrease with long-term bonds,

$$\mathsf{d}R = \mathsf{d}D^B - P_L \mathsf{d}B_L^B, \qquad \langle 5.28 \rangle$$

while similar to non-banks, the bond demand function decreases in the bond price

$$\frac{\partial f^B(P_L, F^B)}{\partial P_L} < 0. \qquad \langle 5.29 \rangle$$

Finally, for the reserve-induced portfolio balance channel to affect long-term bond yields, it must hold that

$$0 < \frac{\partial f^B(P_L, F^B)}{\partial F^B} < 1. \qquad \langle 5.30 \rangle$$

This condition, which establishes a positive link between banks' funding condition and its bond demand, is necessary for the reserve-induced portfolio channel. That is, if banks held any additional deposit funding solely in reserves, such that $\frac{\partial f^B(P_L, F^B)}{\partial F^B} = 0$, then the bond demand would be decoupled from any reserve-induced deposit expansion and LSAPs would only work through the classical supply-induced portfolio balance effect. Taking further into account that over the short horizon of the model, changes in banks' equity valuations do not affect their bond demand, i.e.[45]

$$\frac{\partial f^B(P_L, E^B + D^B)}{\partial F^B} \mathsf{d}E^B = \frac{\partial f^B(P_L, F^B)}{\partial F^B} \mathsf{d}E^B = 0 \qquad \langle 5.31 \rangle$$

[44] As noted above, non-banks are tied to banks via their deposit holdings ($D^{NB} = D^B$).

[45] An alternative interpretation could be that equity valuation changes are paid out as dividends and are therefore not available to fund bond purchases.

means that the flow of banks' bond demand is equal to

$$\mathrm{d}B_L^B = \frac{\partial f^B(P_L, F^B)}{\partial P_L}\mathrm{d}P_L + \frac{\partial f^B(P_L, F^B)}{\partial F^B}\mathrm{d}D^B. \tag{5.32}$$

Transmission Process of LSAPs Given the bond market equilibrium condition and the assumption that overall bond issuance does not react to the increase in bond demand caused by the central bank, LSAPs increase the reserve supply without changing the total supply of bonds ($\mathrm{d}B_L = 0$).[46] As a consequence, LSAPs that increase the central bank's bond holdings are offset by the bond holdings of non-banks and banks, that is

$$\mathrm{d}B_L^{CB} = -\mathrm{d}B_L^{NB} - \mathrm{d}B_L^B \tag{5.33}$$

To analyze the effects of central bank bond purchases and the resulting increase in reserves on the price of bonds, non-banks' bond demand ⟨5.24⟩ and banks' bond demand ⟨5.32⟩ are plugged into equation ⟨5.33⟩ to get[47]

$$\mathrm{d}B_L^{CB} = -\frac{\partial f^{NB}}{\partial P_L}\mathrm{d}P_L - \frac{\partial f^B}{\partial P_L}\mathrm{d}P_L - \frac{\partial f^B}{\partial F^B}\mathrm{d}D^B. \tag{5.34}$$

Now, inserting the non-banks deposit response ⟨5.25⟩ into ⟨5.34⟩ and solving for the bond price reaction to central bank bond purchases, yields

$$\frac{\mathrm{d}P_L}{\mathrm{d}B_L^{CB}} = \frac{-1}{\frac{\partial f^{NB}}{\partial P_L} + \frac{\partial f^B}{\partial P_L} - P_L \frac{\partial f^{NB}}{\partial P_L}\frac{\partial f^B}{\partial F^B}} > 0. \tag{5.35}$$

Here, the first two terms in the denominator represent the standard *supply-induced portfolio balance effects*, which, as described in the previous section, arise from the decrease in the supply of bonds available to the private sector. The third term in the denominator, however, captures the *reserve-induced portfolio balance effect*, which is the focus of this section.[48] Note that this channel is not operating if the price sensitivity of non-banks' demand for bonds is zero, i.e. if $\frac{\partial f^{NB}}{\partial P_L} = 0$, because then the central bank would buy bonds only from banks, which would have no effect on the amount of deposits in the economy.

[46] This is of course another simplifying assumption which might not hold true in practice. Since the year 2008, Greenwood et al. (2014) show that the US Treasury has extended both the total supply as well as the average duration of outstanding Treasury debt while at the same time the Fed tried to shorten the average duration of outstanding Treasury debt. Thereby, Treasury debt management and the Fed's LSAPs pulled the consolidated government balance sheet in opposite directions.

[47] In the following, the arguments of the respective demand functions are dropped for notational simplicity.

[48] Notice that the positivity of equation ⟨5.35⟩ follows from $0 < P_L < 1$ and $0 < \frac{\partial f^B}{\partial F^B} < 1$, which makes the whole denominator negative, although its last term is positive.

Alternatively, the reserve-induced portfolio balance channel shuts down if banks do not react to a change in their deposit base by changing their demand for long-term bonds, i.e. if $\frac{\partial f^B}{\partial F^B} = 0$.

In other words, the reserve-induced portfolio balance effect reinforces the supply-induced portfolio balance effect only if non-banks are on the selling side of central bank LSAPs. Only then do the bond sales cause an autonomous creation of bank deposits, which will, according to equation ⟨5.30⟩, induce banks to reallocate some of their new funding towards long-term bonds. The fact that this additional bond demand has to be met by the supply of non-banks is captured by $P_L \frac{\partial f^{NB}}{\partial P_L}$ in the last term in the denominator of equation ⟨5.35⟩.

Model Extensions In a more realistic version of the model, market participants can also trade *short-term* bonds (B_S). If in this framework the central bank implements LSAPs by buying short-term bonds only, i.e. if $\mathrm{d}B_S^{CB} > 0$ while $\mathrm{d}B_L^{CB} = 0$, the prices of long-term bonds will react nevertheless. As shown in the Appendix B.4, if short-term bonds are purchased from non-banks but not from banks, i.e. if $\frac{\partial f_S^{NB}}{\partial P_S} \to \infty$ and $\frac{\partial f_S^B}{\partial P_S} = 0$, then it holds that

$$\frac{\mathrm{d}P_L}{\mathrm{d}B_S^{CB}} = \frac{-P_S \frac{\partial f_L^B}{F^B}}{\frac{\partial f_L^{NB}}{\partial P_L} + \frac{\partial f_L^B}{\partial P_L} - P_L \frac{\partial f_L^B}{F^B} \frac{\partial f_L^{NB}}{\partial P_L}} > 0. \quad \langle 5.36\rangle$$

The above expression shows that *long-term* bond prices still increase even though the central bank buys solely *short-term* bonds. Furthermore, since the right hand side only depends on the sensitivity of the long-term bond demand with respect to its own price, there is no *supply-induced portfolio balance effect* in this case. In other words, if the central bank buys short-term bonds, any effect on the prices of long-term bonds can be attributed to the *reserve-induced portfolio balance effect*.

As stressed above, a necessary condition for the reserve-induced portfolio balance effect is that the central bank purchases the short-term bonds mainly from non-banks. The bold arrows in Figure 5.11 illustrate this for the polar case when the central bank buys short-term bonds *only* from non-banks.

Because non-banks cannot receive reserves directly, the central bank credits them through the non-banks' deposit accounts with the banking sector.[49] As a result, banks are confronted with an exogenous improvement in stable deposit funding. Under the

[49]Given that short-term bonds and deposits are perfectly substitutable, non-banks have no incentive to engage in supply-induced portfolio adjustments.

Central Bank	
Short bonds ↑ ⇑	Equity
Long bonds	Reserves ↑ ⇑

Non-Banks	
Deposits ⇑	Equity
Short bonds ⇓	
Long bonds	

Banks	
Reserves ↑ ⇑	Equity
Short bonds ↓	Deposits ⇑
Long bonds	

Figure 5.11.: Reserve-induced portfolio channel ⋄ *Operation 1:* Asset purchase from banks (↑). *Operation 2:* Asset purchase from non-banks (⇑). ⋄ *Source:* Christensen and Krogstrup (2016b), own illustration.

assumption that banks viewed their previous portfolio composition as optimal, they will try to sell reserves against longer-term bonds. However, in the aggregate, the banking sector cannot get rid of reserves – and with reserves as the numéraire, their price cannot adjust. In the model, that means the prices of long-term bonds will have to rise for banks to be willing to hold a greater amount of reserves relative to bonds. If, however, for whatever reason, banks are content with their increased reserve holdings, they will not engage in asset substitution and the reserve-induced portfolio balance channel shuts down. In a sense, banks perform the same role as arbitrageurs in the Vayanos-Vila model. One reason why banks could not try to substitute out of reserves is when they are capital-constrained. Banks could become capital-constrained because the balance sheet expansion cause the banks' unweighted capital ratio to decline.

Note that the reserve-induced portfolio balance channel also shuts down if the central bank buys short-term bonds directly from banks. As depicted by the thin arrows in Figure 5.11, this would only amount to an asset swap of two perfectly substitutable assets on banks' balance sheets. Since in reality it is almost impossible to discern whether banks or non-banks are on the selling side of a LSAP program, identifying a reserve-induced portfolio balance effect is ultimately an empirical question.

Empirical Evidence As most LSAP programs were biased towards longer-term bonds, it is almost impossible for empirical studies to disentangle the reserve channel from any supply-induced channels. A notable exception are three unique operations conducted by the Swiss National Bank (SNB) in August 2011. During this episode, the SNB decided to expand reserves from CHF 30 billion to CHF 200 billion (i.e. 30 percent of Swiss GDP) by purchasing only *short-term* government bonds. The goal was to increase the liquidity supply in the Swiss money market to counter the strong appreciation of the Swiss franc.[50] After controlling for potential signalling effects, Christensen and Krogstrup (2016b) conclude that the reserve-induced portfolio balance effect caused the yields of Swiss long-term government bonds to fall by 28 basis points.

A few related studies found supporting evidence for the reserve-induced portfolio balance effect in other jurisdictions. Carpenter et al. (2015) analyze US flow of funds data related to the Fed's LSAP1 (from November 2008 to June 2010); LSAP2 (from November 2010 to June 2011); and the reinvestment program for proceeds of the Fed's maturing MBS holdings (from August 2010 to December 2012).[51] Although the direct counterparties of the Fed's open-market operations are the primary dealers (a subset of banks), Carpenter et al. (2015) uncover that the ultimate counterparts of the Fed's treasury purchases were households (including hedge funds), and to a lesser extend broker-dealers and insurance companies, suggesting that the primary dealers acted mainly as conduits between the Fed and the ultimate seller of the asset. This is an important finding, as it indicates that the Fed purchased mainly from *non-banks*, which, as outlined above, is a crucial condition for the effectiveness of the reserve channel.

5.2. Expectational Channels

5.2.1. Signaling Channel

Theoretical Concept In a frictionless benchmark world populated by Ricardian agents, the Wallace neutrality posits that at the zero lower bound outright purchases of government bonds affect long-term bond yields only if they convey *new information* about the expected path of future short-term rates (Eggertsson and Woodford, 2003; Bhattarai et al., 2015).[52] To further illustrate this point, consider the yield of a default-free government with maturity n, given by

$$y_t^{(n)} = y_{rn,t}^{(n)} + tp_t^{(n)}. \quad \langle 5.37 \rangle$$

[50] Interestingly, despite a constrained policy rate and serious deflationary pressures, the SNB stated no intention to lower longer-term rates with these measures (see the SNB, 2011 press release).

[51] The study does not account for LSAP3, as this program was still active when the paper was first published.

[52] As a corollary, open market operations are also neutral with respect to inflation and real economic activity. For a more detailed discussion on this topic, see section 3.3 .

The long-term yield, $y_t^{(n)}$, can be decomposed into a risk-neutral component, $y_{rn,t}^{(n)}$, and a term premium, $tp_t^{(n)}$. The risk-neutral component equals the expected average short-term policy rate over the lifetime of the bond, while the term premium represents a policy-invariant variable that is determined by the risk characteristic of a bond and the risk aversion of the representative investor.[53] With the current policy rate at the zero lower bound, the only leverage monetary policy has to affect longer-term rates is thus to *signal* a lower path of future policy rates; only then will market participants revise down their expectations for future short-term rates, i.e. lengthen the expected period of zero policy rates. This mechanism after which asset purchases are used to steer interest rate expectations is usually referred to as the *signaling channel* of unconventional monetary policy.

Time-Inconsistency If the signaling channel rests upon investors' expectations about the path of future short-term rates, the question arises why a central bank in a liquidity trap does not simply communicate a lower path of future policy rates? In this respect, the arguments for the signaling channel parallel those of forward guidance (see section 4.1.1). The problem is that if monetary policy follows a Taylor rule based on a purely forward-looking inflation target, the central bank has an incentive to renege on its promise to keep policy rates 'lower for longer' as soon as the inflation rate exceeds its target value. Therefore, a policy that only communicates a lower path of future policy rates thus suffers from a classical *time-inconsistency problem* (Barro and Gordon, 1983).

In principle, the central bank can mitigate this problem by buying assets with longer durations. The reason is that increasing the duration of assets held by an independent central bank provides an incentive for the central bank to keep the policy rate low in the future in order to avoid balance sheet losses. Central bank asset purchases can thus generate inflationary expectations and lower long-term interest rates, which, in turn, stimulates economic activity and reduces the risk of a deflationary spiral, because the asset purchases act as a signal to the public affirming the central bank's *commitment* to its interest rate guidance (see inter alia Woodford, 2012; Bauer and Rudebusch, 2014; Bhattarai et al., 2015).

Asset Horizon and Maturity Range Since the signaling channel is based on the expectations theory of the term structure, it should principally affect a wide range of different

[53]The theoretical rationale for the policy-invariant term premium is given by the no-arbitrage condition of the expectations theory of the term structure. The latter requires that there are no risk-free profits to be made by trading bonds of different maturities.

asset classes. In contrast to 'narrow channels', signaling effects from a particular asset purchase program can thus be expected to spill over to all other fixed-income and securities markets.

A more subtle question is how the signaling channel impacts the cross-section of maturities. To shed light on this issue, consider once again the basic bond pricing equation,

$$P_t^{(n)} = \sum_{j=1}^{n} \frac{CF_j}{(1+i_{j,t})^j}, \qquad \langle 5.38 \rangle$$

which reveals an inverse relation between bond prices and interest rates (where it is assumed that the final cash flow, CF_n, includes the bond's principal payment). If effective signaling leads to a reduction in the average discount factor, bond prices soar and yields decline. As can be seen from ⟨5.38⟩, the size of this effect depends on time to maturity, n, as well as on the length of the downward revision of policy rates. The latter predicts that intermediate bonds might experience the strongest price effect, because in the long run, when the economy (hopefully) recovers, monetary policy will be induced to sell the accumulated assets, thereby causing an upward shift in future discount rates. This upward revision in future spot rates causes long-term bond yields to raise relative to intermediate maturities.

As a simple example, consider three fixed-coupon bonds with maturities of two, five and ten years. Each bond has a face value of 100 and pays a coupon of 0.25% p.a. Now assume that in t, when the level of the short-term rate (i_t) equals 0.25%, the central bank credibly signals that it will lower the short-term rate to 0%. After five years, it is assumed that the short-term rate re-rises to its initial level. Immediately after the announcement, the present value of the two-period bond thus increases to 100.5; the one of the five-period bond to 101.25; and the one of ten-year bond to around 100.009. This simple example illustrates that for reasonable scenarios of the signaling channel, i.e. when the policy rate is lowered for limited time periods, it can be expected that intermediate yields decrease relative to longer-term yields (Krishnamurthy and Vissing-Jorgensen, 2011).

Empirical Evidence In reality, if the central bank is able to effectively signal to market participants its intended path of future policy rates, this might cause a series of interactions with other transmission channels of monetary policy. Very importantly, it dampens interest rate risk, which generates a countervailing impact on the duration risk channel of long-term asset purchases (see section 5.1.1). Additionally, the signaling channel might contribute to a reanchoring of previously unhinged inflation expectations (see section 5.2.2), which should raise real rates compared to a no-policy scenario. Given these repercussions and contingencies as well as the missing counterfactual, it is rather difficult to provide sound empirical evidence for the signaling channel of unconventional policies.

Accordingly, the existing empirical work on the signaling channel comprises a relatively wide range of estimates. In fact, a large part of the literature finds that unconventional policies significantly lowered the term premium on long-term bond yields, and since such a reaction is usually associated with the portfolio balance channel, this is often presented as negative evidence against the signaling channel (see e.g. Meier, 2009; Gagnon et al., 2011b; D'Amico et al., 2012; Altavilla et al., 2015). For a number of reasons, however, jumping to this conclusion might be too hasty.

Firstly, as credible guidance of the policy-rate path reduces the uncertainty about the evolution of future interest rates, the signaling channel has a negative effect on the term premium as well (see also Woodford, 2012, p. 79). Attributing changes in term premia entirely to the portfolio balance channel therefore tends to underestimate the impact of the signaling channel.

Secondly, if expansionary policy announcements produce a more favorable economic outlook, this should marginally *increase* policy-rate expectations in the long-run, which should partly offset the lower policy path signaled by the central bank. And finally, a more technical argument is that conventional arbitrate-free term structure models (DTSM) – like the Kim and Wright (2005) model – include biased estimators that cause the model-implied forecasts for longer horizons to be too close to their unconditional mean. Since this results in an implausibly stable process for the risk-free rate, too much variation in long-term rates is attributed to the term premium component, which in turn overestimates the portfolio balance effect (see e.g. Bauer et al., 2012a; Duffee and Stanton, 2012; Kim and Orphanidis, 2012).

As a consequence, Bauer and Rudebusch (2014) develop a modified DTSM with unbiased estimators generating a short-rate process that reverts much more slowly to its unconditional mean. Their model specification thus predicts a larger contribution of the expectations component to changes in long-term yields and thus also a larger impact of the signaling channel than conventional DTSMs. Hence, while Gagnon et al. (2011b), who use a standard DTSM, estimate that the signaling channel accounted for about 22 percent of the cumulative decrease in 10-year Treasury yields in LSAP1, the unbiased estimates of Bauer and Rudebusch (2014) suggest that it contributed around 40-50 per-

Study	Method	Program	Key results
U.S.			
Gagnon et al. (2011b)	Event study with DTSM	LSAP1	Primary impact through the duration risk channel; no significant impact through the signaling channel
Krishnamurthy and Vissing-Jorgensen (2011)	Model-free event study	LSAP1 & LSAP2	Signaling channel with important role in LSAP1 (20-40 bp of total 107 bp decrease in 10-year Treasury yield). Signaling channel with primary role in LSAP2 (11-16 bp of total 18 bp decrease in 10-year Treasury yield)
Bauer and Rudebusch (2014)	Event study with modified DTSM	LSAP1	Significant effect from signaling channel in LSAP1 (29-53 bp of total 94 bp decrease in 10-year Treasury yield)
Christensen and Rudebusch (2012)	Event study with modified DTSM	LSAP1	Signaling channel with largest impact in LSAP1 (53 bp of total 89 bp decrease in 10-year Treasury yield)
UK			
Joyce et al. (2011a)	Model-free event study and VAR analysis	APF1	In all specifications large impact through portfolio balance channel; no significant impact through the signaling channel
Christensen and Rudebusch (2012)	Event study with modified DTSM	APF1	Primary impact through the portfolio balance channel; no significant impact through the signaling channel
Euro Area			
Altavilla et al. (2015)	Event study with dummy regression	APP	Signaling channel with only modest impact (maximum impact of around 10 bp at a 2-year horizon)

Table 5.8.: Empirical evidence for the signaling channel

cent.[54] In line with these results, Bauer and Neely (2014) show that similar conclusions hold for LSAP2 and LSAP3. Controlling for a number of different model specifications, they estimate that the expectations component on average contributed between 45 and 90 percent to the total decline in long-term interest rates over the Fed's three rounds of quantitative easing.

Interestingly, however, as displayed in Table 5.8, the signaling channel seems to matter less for the UK and the euro area. Possible explanations for this diverging contribution are internationally distinct bond market structures or different central bank communication policies (Christensen and Rudebusch, 2012). Overall, however, it should be noticed that the empirical inference is quite sensitive to the respective model choice.

[54] With restricted risk prices, this entails that LSAP1, through the expectation of lower policy rates, lowered 10-year yields between 29 and 53 basis points (see Bauer and Rudebusch, 2014, p. 261, Table 5.).

5.2.2. Inflation Reanchoring Channel

Theoretical Concept The so-called *inflation reanchoring channel* (Andrade et al., 2016b) is closely related to the signaling channel presented above. Both channels emphasize the effect of central bank asset purchases on the expected path of future policy rates. In contrast to the signaling channel, however, "the reanchoring channel focuses on the information conveyed by the introduction of a quantitative easing program [or any other unconventional monetary policy measure] about the inflation objective of the central bank" (Andrade et al., 2016b, p. 3). If a prolonged period of subdued inflation dynamics *deanchors* the inflation expectations of private market participants, QE can help to *reanchor* them in line with the central banks inflation target. Besides lowering the real interest rate, such a reanchoring of inflation expectations also leads to a lower policy rate in the short- and medium term, because achieving the higher inflation objective requires an easier monetary policy stance. At the same time, it raises interest rate expectations in the long term because the policy intervention causes market agents to update their beliefs about the central bank's inflation objective. This contrasts with the *signaling channel*, where the inflation objective is not questioned, such that the signaling channel predicts no effect on long-term inflation expectations.

Empirical Evidence The obvious empirical strategy to identify the existence of the reanchoring channel is to estimate whether expansionary monetary policy announcements do contribute to increasing inflation expectations. By allowing for such a reanchoring of inflation expectations in the DSGE framework of Gertler and Karadi (2011), the simulations of Andrade et al. (2016b) suggest that the APP as announced by the ECB in January 2015 caused inflation to be 40 basis points and output to be 1.1 percent higher compared to a no-policy scenario. This simulation exercise is cross-checked with a high frequency event study that examines the reaction of survey-based measures of inflation expectations. It suggests that a 10 basis points decrease in the 5-year German Bund yield caused by the APP is accompanied by an increase of around 5 basis points in the 5-year-ahead inflation expectations.

Another event study by the German Bundesbank shows that expansionary monetary policy announcements between October 2009 and July 2011 significantly increased (decreased) inflation (deflation) probabilities as measured by inflation options.[55] Albeit

[55] Inflation options come either as 'inflation caps' or 'inflation floors'. The owner of an inflation cap receives a payment if the inflation rate at the maturity date of the option exceeds a predefined threshold (vice versa for an inflation floor).

this exercise fails to identify a significant effect of monetary policy surprises on option-implied inflation expectations between August 2011 and December 2013, it does suggest that policy reactions in 2014 contributed to a substantial reduction in deflationary risks.[56] In September 2014, the outright asset purchases began with the announcement that the ECB would purchase asset-backed securities and covered bonds. The program was then scaled up in January 2015 with the announcement of the public sector purchase program. Together, these purchases contributed to a reanchoring of inflation expectations in line with the ECB's medium-term objective of 2 percent. Moreover, it has been instrumental in reversing the rise in real rates that could have been observed since the beginning of 2015. The euro area 5-year real rate had risen by about 60 basis points between September 2014 and January 2015, but it then fell by about 85 basis points between mid-January and April 2015 (Draghi, 2015a).

Empirical studies that use alternative market-based measures of inflation expectations largely confirm this result. For instance, the event study of Altavilla et al. (2015) relying on inflation swap rates suggests that the ECB's asset purchase program increased 5-year inflation expectations by between 14 and 24 basis points.[57] Using a similar approach for the Fed's first two rounds of QE, Krishnamurthy and Vissing-Jorgensen (2011) find that 10-year inflation expectations in the US rose by around 96 basis points and 5 basis points, respectively.[58] Overall, this empirical evidence generally supports the view that QE is an effective policy tool to stabilize inflation expectations – particularly at times of heightened uncertainty concerning a central bank's inflation objective.

5.2.3. Market Functioning Channel

Asset Pricing and Liquidity Risk Asset pricing models that account for liquidity risk demonstrate a negative correlation between asset returns and the liquidity (or marketability) of an asset (Amihud and Mendelson, 1986; Acharya and Pederson, 2005).[59] As

[56] See also Scharnagl and Stapf (2014).

[57] An inflation swap is a financial derivative used to hedge against inflation risk by an exchange of net cash flows. In an inflation swap, the fixed-rate payer pays a predefined rate on some notional amount, while the other party pays a floating rate linked to the evolution of the consumer price index over the life of the swap. Since the fixed-rate payment is agreed upon the initiation of the swap, it reflects the expected inflation rate over the maturity of the contract.

[58] These figures are largely confirmed by alternative measures of inflation expectations, like the break-even inflation rate (BEIR), for instance. The BEIR is equal to the difference between the yield on inflation-indexed government bonds and the yield of an otherwise identical nominal government bond. For the pros and cons of different market-based measures of inflation expectations, see e.g. Bundesbank (2015a).

[59] Consistent with the economic literature, the terms 'liquidity' and 'market functioning' are used interchangeably in this section.

investors value liquidity particularly during times of heightened market uncertainty, liquidity premia tend to move in a countercyclical fashion (Duffie et al., 2003; Longstaff et al., 2005). In turn, Amihud and Mendelson (1991) document a liquidity premium for US Treasuries, while Beber et al. (2009) show that different degrees of liquidity risks are a dominant factor determining the yield spreads between euro area sovereign bonds.

Market Functioning and UMP The largest issuers of mortgage-backed securities are the three US government-sponsored agencies (GSEs); Fannie Mae, Freddie Mac, and Ginnie Mae. These institutions assemble loans made by individual lenders into a pool and then issue MBS which represent a claim on the principal and interest of the mortgage loans in the pool. Thereby, the GSEs guarantee the timely payment of principal and interest of the MBS, even if the underlying mortgages default. Collectively, the MBS backed by these institutions are known as agency MBS. Since the GSEs themselves enjoy an implicit guarantee of the US Federal government, agency MBS carry essentially zero default risk (Passmore, 2005).

Given the size and depth of the US mortgage market, agency MBS represent highly liquid securities with relatively low risk. With the failure of Lehman Brothers, however, the market for agency MBS essentially froze, which caused a spike in the spread between agency MBS and US Treasury yields.[60] Since the government guarantee implies that both types of securities carry essentially no credit risk, the spreads largely reflected liquidity risk premiums on MBS (see Figure 5.12).[61]

Besides the secondary MBS spread and the holdings of MBS as accounted on the Fed's balance sheet, the dashed vertical lines in Figure 5.12 display the announcement dates of the three rounds of asset purchases that included security purchases of housing GSEs. LSAP1 was announced in November 2008 and involved $1.25 trillion of agency MBS and $172 billion of debt securities issued by the housing GSEs. The second round of purchases was announced in September 2011 through the reinvesting of principal payments from the Fed's agency MBS and debt holdings. Finally, in September 2012, the

[60] In normal times, there is a small positive spread between agency MBS and US Treasury yields, which can be attributed to the higher convexity risk in MBS. The higher convexity risk arises because most US mortgages can be prepaid at any time during the life of the mortgage. That is, when interest rates fall, borrowers choose to prepay their existing mortgage and refinance into a new mortgage with lower rates. This prepayment option thus poses a risk to MBS holders, as they get more prepaid principal which they have to reinvest at lower yields.

[61] Another explanation for the high yield spread is that most banks at that time were severely capital-constraint. This puts agency-related debt at a disadvantage relative to Treasury bonds, since agency bonds carry a 20 percent risk weight, while Treasury bonds have a weight of 0 (Gagnon et al., 2011b; Krishnamurthy and Vissing-Jorgensen, 2013).

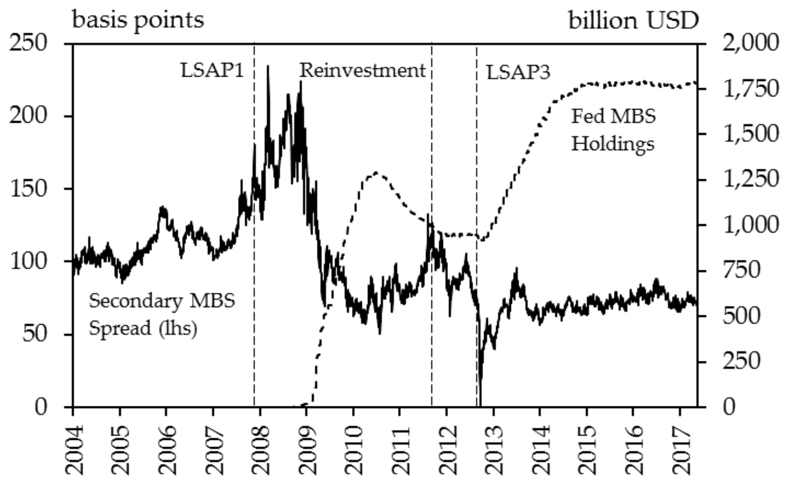

Figure 5.12.: Secondary mortgage spread (lhs) and Federal Reserve MBS holdings (rhs) ⋄ The secondary MBS spread is the yield spread between the Fannie Mae 30-year current-coupon MBS and the 10-year US Treasury yield. The maturity difference between both series captures the fact that most 30-year MBS are typically paid off or refinanced before their maturity date. ⋄ *Source:* Bloomberg, Datastream

Fed announced that it would purchase additional agency MBS at a pace of $40 billion per month and continue to reinvest principal payments in GSE MBS.

It is now widely acknowledged that the Fed's initial MBS purchases program from 2009-2010 was an important component in the restoration of the agency MBS market (see e.g. Hancock and Passmore, 2011; Gagnon et al., 2011b; Krishnamurthy and Vissing-Jorgensen, 2011). As the Fed's large-scale asset purchases provided an ongoing source of demand for principally illiquid MBS, it jump-started private trading activity. Moreover, since private investors could reasonably expect to sell their assets to the Fed, the secondary MBS spread settled even below its pre-crisis level with the completion of LSAP1 in March 2010. The market functioning channel thus works by reassuring market participants that there is reliable deep-pocket investor who stands ready to purchase the distressed securities at any price and under all market conditions.

Empirical Evidence Consequently, Hancock and Passmore (2011) estimate that the Fed's first announcement of MBS purchases in November 2008 reduced US mortgage rates by about 100 basis points. In particular, they find that about half of this decline resulted from improved market functioning, while the other half came from portfolio rebalancing. Since the MBS market was functioning more normally after the completion of LSAP1, subsequent MBS purchase programs had a much lesser impact. This state-dependent impact of the Fed's MBS purchases is in line with other statistical findings. Krishnamurthy and Vissing-Jorgensen (2011), for instance, estimate that agency 10-year MBS yields in the course of LSAP1 declined by 107 basis points, while they fell by only 13 basis points during LSAP2. Furthermore, Gagnon et al. (2011b) find that 30-year agency MBS yields declined by a total of 113 basis points throughout LSAP1.[62]

In this context, a common perception is that central bank interventions in a particular market could also exert a negative impact on market functioning, for instance by crowding out private market activity. In 2013, this was also acknowledged by the Board of Governors of the Federal Reserve, which noted that "one potential cost of conducting additional [large-scale asset purchases] is that the operations could lead to a deterioration in market functioning or liquidity in markets where the Federal Reserve is engaged in purchasing. More specifically, if the Federal Reserve becomes too dominant a buyer in a certain market, trading among private participants could decrease enough that market liquidity and price discovery become impaired." (Board of Governors of the Federal Reserve System, 2013b). Albeit the effectiveness of MBS purchases indeed decreased over time, at least no clear-cut negative effects can be identified for the Fed's subsequent MBS purchases (Kandrac, 2014).

With respect to the euro area, Ejsing et al. (2012) demonstrate that liquidity risks played an important role in driving the yield spread between French and German government bonds during the financial crisis of 2008/2009. The spread between both sovereigns increased from quasi zero before July 2007 to around 50 basis points in January 2009, and to more than 70 basis points in the midst of the European sovereign debt crisis in 2011/2012. If the spread only reflected higher credit risk associated with the French government, a similar spread should have opened up between the yields on government-guaranteed agencies of both countries. However, the spread between French and German agency bonds remained comparably low during 2008/2009, while they increased considerably during 2011/2012. This pattern – a wide sovereign spread together with a tight agency spread – suggests that increased liquidity risk and not increased credit risk was responsible for the yield differentials between both countries in the early stages of the financial crisis. However, this seems to have changed during the sovereign debt crisis. As French agency bonds began to trade at premium compared to German agency bonds, it seems that the cross-country spreads at this stage were dri-

[62] Another factor contributing to the relatively large impact of LSAP1 could be that markets viewed the first program as a credible signal that fostered the implicit government guarantee of Fannie Mae and Freddie Mac (Stroebel and Taylor, 2012).

ven to a large extent by different degrees of credit risk. With the introduction of OMT and the subsequent large-scale public sector purchase program, however, these spreads started to vanish. Given that a wide array of measures had already been implemented by the ECB before the announcement of OMT and PSPP, it is almost impossible to estimate whether the market functioning channel was an important component of these measures. However, tentative evidence suggests that it played at least some part for the periphery countries (see, for example, Altavilla et al., 2016; Falagiarda et al., 2015.)[63]

5.3. Spillover Effects

In the previous theoretical analysis, it has been emphasized that whether one can expect unconventional asset purchases to have significant spillover effects to other asset prices depends critically on the prevalence of certain transmission channels. Specifically, while portfolio rebalancing to risky assets should be comparatively low in times of heightened market uncertainty (local supply channel/safety channel), spillover effects can be expected to be more pronounced during normal times (duration channel).

In the following, I will therefore briefly review the existing empirical evidence on the domestic as well as international spillover effects of unconventional measures in the US and the UK, before I will turn to a more thorough analysis of the spillover effects of the ECB's extended asset purchase program in section 6.2.1.

5.3.1. Domestic Spillover Effects

Conceptually, the only real difference between domestic and international portfolio balance channels is the need to compare asset returns in a common currency. Despite the similarity in the transmission mechanism, however, far more studies exist that assess the domestic spillover effects from unconventional monetary policies. Accordingly, for both the US Federal Reserve and the Bank of England, a series of studies document significant and economically substantial yield declines beyond those securities targeted for purchase.

For example, Gagnon et al. (2011b) estimate that the Federal Reserve's first asset purchase program – which included Treasury bonds, agency debt and agency MBS – lowered US Baa corporate bond yields by around 67 basis points. Since 10-year Treasury

[63] Joyce and Tong (2012) find positive evidence for the market functioning channel within the UK.

yields fell by 'only' 91 basis points, this points to widespread domestic spillover effect from LSAP1. Moreover, Krishnamurthy and Vissing-Jorgensen (2011) document that both LSAP1 and LSAP2 caused a substantial decline in Baa long-term corporate yields.[64] In addition, they find that 10-year CDS rates on Baa corporate bonds decreased considerably throughout LSAP1 – suggesting that the reduction in private borrowing costs for domestic non-financial corporations acted mainly through a mitigation of default risk (see also Gilchrist and Zakrajsek, 2013).

Finally, the event study by Haldane et al. (2016) documents a relatively large cross-country heterogeneity in domestic spillover effects. While domestic corporate bond yields experienced a substantial decline in the UK and the US, private borrowing costs exhibited only a moderate decline following the QE announcements in Japan and the euro area.[65]

Interestingly, cross-country differences exist also in the reaction of equity markets. As depicted in Figure 5.13, the positive reaction of equity indices to QE announcements seem to increase with the size of the program, although this pattern is far from uniform. In fact, at some dates policy announcements might have even disappointed market expectations, which could explain the fall in equity prices at those events. Alternatively, the variation in domestic spillover effects over time and across countries could depend on different states of financial markets. In turn, Georgiadis and Gräb (2016) show that the boost in euro area equities following the ECB's APP announcement has been mainly driven by the confidence and signaling channel, while euro area equities during earlier measures (especially OMT and SMP) seem to have benefited through the portfolio rebalancing channel. Irrespective of the specific transmission channels at work, however, the overall empirical evidence supports the notion that central bank asset purchases are generally associated with positive spillover effects to non-targeted asset classes.

[64]Besides a smaller event sample, the results of Krishnamurthy and Vissing-Jorgensen (2011) reflect two-day changes, whereas Gagnon et al. (2011b) estimate one-day changes.

[65]Haldane considers the following eight event dates for the BoE: March 5, 2009; May 7, 2009; August 6, 2009; November 5, 2009; October 6, 2011; February 9, 2012; July 5, 2012; August 4, 2016. Five events for the Federal Reserve: November 25, 2008; March 18, 2009; November 3, 2010; September 13, 2012; December 12, 2012. Four events for the ECB: September 4, 2014; January 22, 2015; December 3, 2015; March 10, 2016; and two events for the BoJ: April 4, 2013; October 31, 2014. The estimations are measured as two-day changes around the respective event dates.

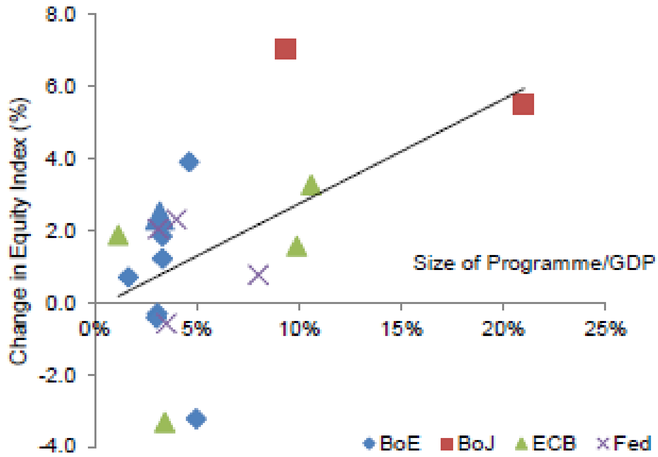

Figure 5.13.: Change in equity indices around QE announcements ⋄ Equity indices are FTSE All Share (UK), S&P 500 (US), Euro Stoxx 300 (Euro Zone), and Topix (Japan) ⋄ Changes measured over two-day windows around QE events ⋄ *Source:* Haldane et al. (2016, p. 16)

5.3.2. International Spillover Effects

Depending on the degree of substitutability between domestic and foreign assets, LSAPs might have large international effects. More precisely, if investors regard foreign securities as closer substitutes for domestic securities than reserves, they might rebalance their portfolios towards these foreign securities following reserve-financed asset purchases by the central bank (Neely, 2015). As a consequence, the prices of foreign securities rise while the home currency depreciates. Importantly, such international spillover effects can be expected to increase with the amount of foreign sellers in an asset purchase program, as the latter are more likely to invest the additional reserves in foreign rather than domestic assets (Benford et al., 2009). Firstly, however, investors abroad need to exchange the domestic reserves for foreign currency in order to buy the foreign securities – which causes the home currency to depreciate. Therefore, this mechanism is usually referred to as the *exchange rate channel* of unconventional policies.

Accordingly, Haldane et al. (2016) show that most asset purchase announcements led to a depreciation of the respective country's nominal effective exchange rate (see Figure 5.14). This broad finding is validated by a series of alternative studies. Neely (2015), for instance, documents that the Fed's unconventional policy measures of 2008-2009 decreased both international bond yields as well as the value of the US dollar vis-à-vis its main trading partners. Additionally, the analysis reveals that most of this reaction can

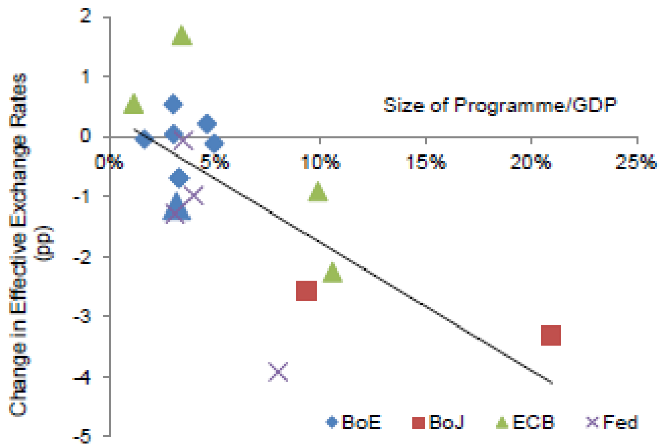

Figure 5.14.: Effective exchange rates around QE announcements ⋄ Negative values denote a depreciation of the respective currency ⋄ Changes measured over two-day windows around QE events ⋄ *Source:* Haldane et al. (2016, p. 15)

be attributed to an international portfolio rebalancing effect, which was mainly directed towards developed countries.[66]

For the ECB's unconventional monetary policy measures (excluding the APP), Rogers et al. (2014) find that they had much smaller international effects than those in the US. Consistently, Fratzscher et al. (2016a) show that OMT, SMP as well as the ECB's non-standard supplementary LTROs – albeit boosting global equity markets and lowering credit risk among G20 banks and sovereigns – did not lead to large international portfolio rebalancing across assets and countries.[67] Interestingly, however, this stands in stark contrast to the APP, which did have large international effects; by supporting investor confidence and reducing the risk of a persistent stagnation in the euro area, it caused a broad-based depreciation of the euro and boosted security prices around the world (Georgiadis and Gräb, 2016; Altavilla et al., 2015).

Overall, these results imply that central banks around the globe should coordinate

[66]In a refined study assessing in more detail the determinants of the international spillover effects of the Fed's three LSAPs, Bauer and Neely (2014) find a more heterogeneous response across countries. While large international spillover effects can be observed for all countries under consideration, the signaling channel seems to be dominant for the US and Canada. For Germany and Australia, however, the portfolio balance channel appear to have played a relatively larger role, while being the only channel for Japanese yields.

[67]Falagiarda et al. (2015) focus on the ECB's unconventional monetary policy spillovers to non-euro area countries from Central and Eastern Europe (the Czech Republic, Hungary, Poland and Romania). While they find that SMP announcements had large spillover effects, OMT and PSPP announcements seemed to have had significantly lesser effects on those countries.

their policies in order to avoid either contractionary exchange rate movements abroad or overly stimulative effects at home.

International Spillover Effects and Financial Stability The global spillover effects from advanced economies' unconventional monetary policies were not welcomed by all of its recipients. Policy makers particularly of emerging market economies (EMEs) complained rather forcefully against the large and potentially destabilizing swings in international capital flows. For instance, in November 2010, when Ben Bernanke announced the second round of LSAPs in the US, the Brazilian finance minister Guido Mantega accused the Fed of waging a *currency war*. Against this backdrop, emerging market policymakers criticized the major central banks for having created excessive global liquidity, which spurred asset price bubbles and an unsustainable credit expansion. This so-called *global currency channel* is particularly pronounced in the case of the US dollar. In fact, recent data published by the Bank of International Settlements shows that the outstanding stock of US dollar-denominated credit to non-bank borrowers outside the United States – a key indicator of global liquidity conditions – peaked at $10.5 trillion by the end of 2016 (BIS, 2017).

Up to this point, US dollar credit to non-bank EME borrowers almost doubled between 2008 and 2016, reaching $3.6 trillion at the end of that period. This strong external role of the dollar implies that changes in the US monetary policy stance can have substantial spillovers to financial conditions elsewhere. In the following, I will thus briefly address the concerns related to financial stability. Given the pre-eminent role of the US dollar as the key currency that underpins the global banking system, the discussion will focus on the international dimension of the Fed's unconventional policies.

While the Fed's first QE program of 2008-2009 triggered a repatriation of foreign portfolio investments into US equity markets, the capital flows reversed during QE2 and QE3 (Fratzscher et al., 2016b). In this way, US policy measures actually increased the pro-cyclicality of capital flows for emerging market economies. And since these results suggest a link between the macro conditions in major financial centers and the transmission of portfolio flows to periphery countries, it could be seen as positive evidence for the *risk-taking channel* of unconventional monetary policies (Rey, 2013; Bruno and Shin, 2015).

Another aspect that is often cited in the context of financial spillovers from unconventional monetary policies is the so-called *taper tantrum* of 2013. It refers to an episode when the Fed's intimations to slow down its monthly asset purchases in the light of a robust economic recovery caused great turbulence on global financial markets. Given the substantial dollar borrowings of emerging market financial and non-financial corporations, the sudden reversal of capital flows out of emerging market economies increased the financial stability risks in those countries significantly.

Despite those financial spillovers, the debate whether the expansionary monetary policies of the advanced economies are indeed responsible for the increased fragility of emerging market economies has not been settled yet. In fact, the hypothesis is challenged by academics and policy makers alike. Bernanke (2016), for instance, argues that in order to get a complete picture of the international effects of the Fed's unconventional policies, one has to compare the *expenditure-augmenting effects* of these policies (adding to global aggregate demand through higher domestic income) with the *expenditure-switching effects* (adding to domestic demand through a weaker currency and higher exports at the expense of others).

Actually, in 2008-2009, net exports did cushion the contraction in real GDP following the failure of Lehman Brothers, since the recession led US imports to shrink more than its exports (see Figure 5.15). Interestingly, however, net exports in this period improved even though the dollar experienced a sharp *appreciation*, as global investors rushed for the safety of US dollar assets (see Figure 5.16). Moreover, during the episode of the Fed's alleged currency war from 2010-2014 the contribution of net exports to US GDP was negligible. And while the US dollar, after the announcement of LSAP2 in late 2010, in fact depreciated against many emerging market currencies, it started a persistent recovery since mid-2011.

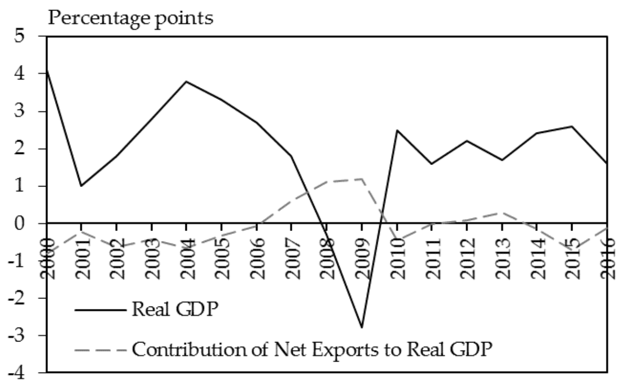

Figure 5.15.: Contribution of net exports to annual US real GDP growth ◇
Source: Bureau of Economic Analysis

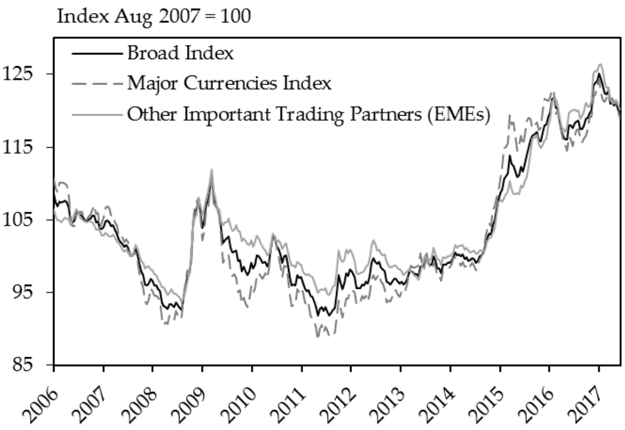

Figure 5.16.: Trade-weighted US foreign exchange rate ⋄ The 'Broad Index' is a weighted average of 'Major Currencies' (euro area, Canada, Japan, UK, Switzerland, Australia, and Sweden) and 'Other Important Partners' (Mexico, China, Taiwan, Korea, Singapore, Hong Kong, Malaysia, Brazil, Thailand, Philippines, Indonesia, India, Saudia Arabia, Russia, Argentina, Venezuela, Chile, and Colombia) ⋄ 'Other Important Partners' thus constitute a reasonable proxy for emerging market economies (EMEs) ⋄ *Source:* Fed Fred.

Thus, one can conclude that the recent recovery of the US economy was certainly not driven by net exports. Instead, the expenditure-switching and the expenditure-augmenting effects of the Fed's unconventional policy operations seem to have essentially offset each other (Ammer et al., 2016). Thus, the accusations that the Fed waged a currency war do not hold in practice.

Rather, the concerns of emerging market policymakers about currency wars can be explained in the context of the classical *policy trilemma* (Bernanke, 2016). The main reason is that emerging market central banks, beyond their internal objectives of price and output stability, often pursue additional exchange rate objectives, as export promotion through undervaluation has become a linchpin in the growth strategies for many of these countries. As a consequence, however, the managed exchange rates cannot sufficiently adjust to shield the EMEs from excessive capital flows. From a policy perspective, emerging market economies should thus either drop their exchange rate objectives, or implement capital controls as macroprudential policy tools. Thus, the question whether to (re-)introduce capital controls – for instance through regulatory caps on foreign credit – is currently being vividly discussed in academia and policy circles alike (see, inter alia: Jeanne and Korinek, 2010; Farhi and Werning, 2012; Eichengreen and Rose, 2014; International Monetary Fund, 2016; and Andreasen et al., 2017).

6. Financial Market Effects of the ECB's Asset Purchase Program

6.1. The ECB's Asset Purchase Program

The ECB's asset purchase program (henceforth APP) started in October 2014 with the purchase of euro-denominated covered bonds (CBPP3) and asset-backed securities (ABSPP) of the private sector.[1] Until January 2015, average monthly purchases under the CBPP3 accounted for about €12 billion, and purchases under ABSPP for about €1.5 billion per month.[2] This changed on January 22, 2015, when the Governing Council in the face of weak euro area inflation dynamics and signs of reductions in longer-term inflation expectations announced that the APP should be expanded to include a large-scale public sector purchase program (PSPP). Consequently, the combined purchases of private and public sector securities were increased to €60 billion per month, which were intended to be carried out until September 2016. Therefore, markets could have inferred that the overall size of the APP should be around €1.14 trillion.[3]

Since these €1.14 trillion equal about 11% of 2014 euro area GDP, the size of the extended APP was largely comparable to the first rounds of QE in the US and the UK. In contrast to the latter, however, the APP was announced under relatively calm financial market conditions. This point is also underlined in Figure 6.1, which depicts the spread between the Merill Lynch index measuring the yields of BBB-rated US (euro area) corporate bonds and the yields of essentially risk-free US (German) government bonds.

[1] As outlined above, the ECB had previously offered a series of unconventional liquidity provisions (1y-3y LTROs), as well as some small-scale asset purchase programs (SMP, ABSPP, CBPP1, CBPP2). However, these programs were mainly geared towards stabilizing interbank markets, but did not directly aim at stimulating economic activity or the inflation rate.

[2] The CBPP and ABSPP program had been announced on September 04, 2014. Yet purchases under the CBPP did not start before October 24, 2014, and purchases under the ABSPP not before December 02, 2014.

[3] The APP announcement did not include a binding commitment to end the purchases at September 2016. In fact, the APP was announced as an open-ended program the size and duration of which were made conditional on the path of the euro area inflation rate, thus sharing some features of state-contingent forward guidance for monetary policy rates.

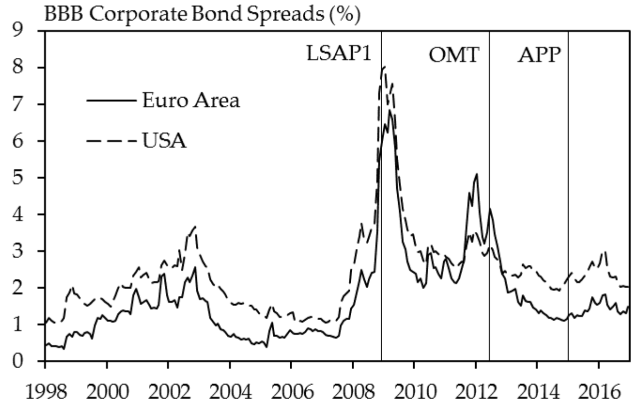

Figure 6.1.: US and EA BBB corporate bond spreads over government bonds ◇ The vertical lines depict the announcements of the various asset purchase programs (LSAP1 for the US, OMT and APP for the EA) ◇ *Source:* Merill Lynch, Datastream.

Thus, the spread measures the risk premium investors require to hold US (euro area) corporate bonds. As an approximation, the quantity of credit risk reflected in the BBB corporate bond spread is presumably constant, because bonds with deteriorating credit ratings are removed from the index. Nevertheless, the spread shows considerable fluctuations over time. If, as can be fairly assumed, the risk aversion of investors is rather constant, fluctuations in the spread must ultimately be driven by changes in macroeconomic uncertainty (see also Figure 4.7). The left vertical line in Figure 6.1 shows that the Fed launched its LSAP1 when uncertainty in credit markets was highly elevated. To a lesser extent, this also true for the announcement of the ECB's outright monetary transactions (OMT), which was initiated in the midst of the euro area debt crisis. In contrast, the APP was announced at times when the euro area corporate bond spread had already fallen below its historical average of about 1.73%, i.e. when bond risk premia were already substantially compressed. In such an environment, however, the model of the previous section predicts that central bank asset purchases have a smaller impact on long-term interest rates than in times of heightened uncertainty. In particular, while the duration channel and the credit risk channel for distressed euro area sovereigns might still be effective, we would expect the APP to have only a minor impact via the local supply channel.

6.2. Event Study Specification

To assess the overall effectiveness of the ECB's public sector purchase program, I use the event study framework to measure if sovereign and corporate bond yields changed significantly on certain (important) announcement dates.[4] Obviously, selecting the event dates carefully is a prerequisite to be able to draw causal conclusions regarding the impact of the program. In particular, focusing on the announcement and implementation dates would be inappropriate in our case. The reason is that market participants increasingly expected the ECB's operation before it was officially announced, not only because LSAPs had been successfully implemented by other central banks, but also because the likelihood of an asset purchase program has already been implicitly communicated to the market in the course of the second half of 2014.[5]

Furthermore, after the implementation of the first round of government bond purchases (March 09, 2015), I consider only press conferences as event dates that included at least indirect news with respect to asset purchases. The rational is that market agents became increasingly accustomed to the contingencies for potential APP adjustments, such that inflation and output developments arguably became more important than official central bank communication.

In the following, I perform an extended event-study to estimate the overall APP's effectiveness. Compared to existing event studies, like those by Altavilla et al. (2015) and De Santis (2016), for instance, I use a wider and more contemporary data set concerning the APP event dates (Table 6.1 lists all event dates included in our baseline approach). Therefore, I can account for the variations in the size and composition of the program that were implemented in the period between March 2015 and December 2016. While the results from the previous studies suggest that the APP successfully lowered yields mainly at its beginning, I am able to draw conclusions regarding the overall effectiveness of the program.

[4]This section is based on joint work with my colleague Konstantin Kuck. I gratefully acknowledge access to Datastream/Bloomberg etc. provided by DALAHO, University of Hohenheim.

[5]That markets expected asset purchase programs before they were officially announced could also explain why traditional event studies find a lower yield impact for the second and third rounds of QE in the US and the UK (Cahill et al., 2013; Martin and Milas, 2012).

Date	Event Description
Mar. 25, 2014	Draghi speech at the Science Po, Paris. First tentative indication of the possibility of asset purchases (Draghi, 2014a).
Apr. 24, 2014	Draghi speech at the Conference De Nederlandsche Bank 200 years, Amsterdam. Further indication of asset purchase program contingent on deteriorating inflation (Draghi, 2014g).
Aug. 22, 2014	Draghi speech at Jackson Hole emphasizing a deteriorating outlook of inflation. Stronger indication of upcoming asset purchases (Draghi, 2014j).
Sept. 04, 2014	ECB press conference: Announcement of ABS purchase program (ABSPP) and new covered bond purchase program (CBPP3). Decision to lower main refinancing rate by 10 basis points to 0.05% and deposit facility rate to -0.20% (ECB, 2014a).
Sept. 12, 2014	News conference following a meeting of Euro Area Finance Ministers in Milan.
Sept. 24, 2014	Draghi interview with Europe1 (Draghi, 2014d).
Sept. 25, 2014	Draghi interview with Lithuanian business daily Verslo Zinios (Draghi, 2014c).
Oct. 02, 2014	ECB press conference announcing operational details of ABSPP and CBPP3 (ECB, 2014b).
Oct. 10, 2014	Draghi statement at the annual IMF Meeting, Washington DC (Draghi, 2014i).
Oct. 24, 2014	Draghi speech at the Euro Area Summit, Brussels (Draghi, 2014b).
Nov. 06, 2014	ECB press conference: First time that introductory statement includes reference to the ECB's balance sheet. Further statement that Governing Council is unanimous in its commitment to using additional unconventional instruments within its mandate (ECB, 2014c).
Nov. 17, 2014	Draghi introductory remarks at the Economic and Monetary Affairs Committee of the European Parliament (Draghi, 2014e).
Nov. 21, 2014	Draghi speech at the Frankfurt European Banking Congress (Draghi, 2014h).
Nov. 27, 2014	Draghi introductory remarks at the Finish parliament and speech at the University of Helsinki (Draghi, 2014f).
Dec. 04, 2014	ECB press conference: no change in policy measures but further hints of upcoming QE (ECB, 2014d).
Jan. 02, 2015	Draghi interview with Handelsblatt (Draghi, 2015c).
Jan. 08, 2015	Draghi letter to European Parliament (Draghi, 2015d).
Jan. 14, 2015	Draghi interview with 'Die Zeit' (Draghi, 2015b).
Jan. 22, 2015	ECB press conference. At 14:40 EST announcement to purchase Euro Area public and private sector securities (PSPP) for €60 billion per month until Sept. 16. Information on eligible maturities announced at 15:10 EST (ECB, 2015d).
Mar. 05, 2015	ECB press conference: announcement to start PSPP at Mar. 09, 2015 (ECB, 2015e).
Mar. 09, 2015	ECB starts with the implementation of QE.
Jul. 16, 2015	ECB press conference: tentative evidence of further QE (ECB, 2015f).
Sep. 03, 2015	ECB press conference: issuer limit for total asset purchases increased from 25% to 33% (ECB, 2015g).
Oct. 22, 2015	ECB press conference: no change in policy measures but signal for further accommodation by stating that "the asset purchase programme provides sufficient flexibility in terms of adjusting its size, composition and duration (ECB, 2015h)."

Jan. 21, 2016	ECB press conference: strong indication that PSPP will be enlarged in March 2016 given the weak Euro Area inflation and growth rate (ECB, 2016d).
Mar. 10, 2016	ECB press conference: enlargement of purchase program to €80 billion per month at least until March 2017. Announcement that asset purchases can also include corporate bonds of the private sector (CSPP). Additional announcement to launch four targeted long-term refinancing operations (TLTRO2) with maturity of four years beginning in June 2016. Decision to lower deposit facility rate to -0.40% and, in Q&A, the remark that helicopter money is a very interesting concept (ECB, 2016c).
Jun. 02, 2016	ECB press conference: announcement to start CSPP on Jun. 08, 2016 and timing information concerning TLTRO2 (ECB, 2016e).
Oct. 20, 2016	ECB press conference: indication the QE will be prolonged in December 2016 (ECB, 2016f).
Dec. 08, 2016	ECB press conference: QE is extended beyond March 2017 and will continue at monthly purchases of €60 billion at least until December 2017. Maturity range increased from 2-30 years to 1-30 years. Furthermore, bonds with yields below deposit facility rate are made eligible for purchase (ECB, 2016g).

Table 6.1.: APP baseline event dates

I study the overall effect of the ECB's purchase program on the basis of a dummy regressions of the form,

$$\Delta y_t = \alpha + \theta \Delta y_{t-1} + \sum_{j=1}^{k} \beta_j D_{j,t} + \sum_{j=1}^{k} \gamma_j D_{j,t-1} + \epsilon_t, \qquad \langle 6.1 \rangle$$

where Δy_t is the close-to-close (one-day) change in bond yields, or the (daily) return of a given asset, α is a constant, and $D_{j,t}$ is a dummy variable that takes the value of 1 at the event date j and zero otherwise.[6] The total estimated one-day (yield) effect due to the APP equals the sum of the β_j coefficients over all of the k event dates considered. The overall effect of the ECB's purchase program, hence, is estimated as the cumulated yield change around the identified policy events. Likewise, the two-day effects are given by the sum of the β_j and γ_j coefficients.[7] To assess the statistical relevance of the estimated effect, I perform a Wald-type test to see whether the sum over all β_j (or both β_j and γ_j) coefficients is significantly different from zero.

[6]Note, if necessary, I included additional lags of the dependent variable in order to correctly specify Equation 6.1.

[7]Estimating Equation 6.1 using a series of two-day changes resulted in strong (artificial) autocorrelation issues in the error term, implying a model misspecification. From an econometric perspective, measuring two-day changes as cumulative sum of the coefficients on both the dummies and the lagged dummies, β_j and γ_j, thus seemed more suitable.

Beyond that, I follow Altavilla et al. (2015) and carry out a 'controlled' event study to mitigate the risk that estimates are confounded by other factors affecting the assets under consideration. Specifically, I use a second specification, where I include the change in the Bloomberg News Index as control variable[8]:

$$\Delta y_t = \alpha + \theta \Delta y_{t-1} + \sum_{j=1}^{k} \beta_j D_{j,t} + \sum_{j=1}^{k} \gamma_j D_{j,t-1} + \eta_1 \Delta News_t + \eta_2 \Delta News_{t-1} + \epsilon_t, \quad \langle 6.2 \rangle$$

This variable quantifies in one measure the extent to which macroeconomic indicators exceed or fall short of consensus estimates. By including this variable, I try to isolate the effect of the asset purchase program on our dependent variables. In the following, I choose the controlled study as my baseline specification.

6.2.1. Event Study Results

Effects on Sovereign Yields Table 6.2 summarizes the impact of the APP on sovereign and corporate bond yields and the other assets under consideration. Panel (a) displays the estimated one- and two-day changes in the government bond yields of the four biggest euro area countries (Germany, France, Italy, Spain) as well as the GDP-weighted change in yields of euro area government bonds. First, the results reveal a substantial cross-country heterogeneity in the yield response of the selected euro area countries. For instance, for one-day yield changes in the 10-year maturity bucket, the results range from insignificant -35 basis points for German Bunds, to highly significant -112 basis points for Italian government bonds. Second, across all maturities, I observe the strongest response in bond for Italy and Spain. Moreover, the estimated responses to the APP are significant for all countries and across maturities, except for German bonds when looking at one-day changes.

Another interesting finding is that yield changes appear amplified and longer-term yields generally declined more than short-term yields once a two-day event window is considered. In fact, yields across all maturities show a substantially more pronounced effect in case of the two-day specification. One possible explanation for these differences with respect to the window length could be that more time was needed for the policy events to feed through to longer durations. This may lend further support to the hypot-

[8] First differences are preferred since yield changes are stationary variables whereas the level of news index rather seems to be $I(1)$. Using the first differences of the news index hence has the advantage that all variables in Equation 6.2 exhibit the same order of integration.

hesis that market participants needed some time to 'digest' the news about the APP policy events.

This substantial cross-country heterogeneity has interesting implications with regard to the transmission channels of the APP. Assuming that the Eurosystem buys roughly the same maturity bucket for each eligible euro area country, the different yield reactions should be largely attributable to the different degrees of credit risk of the respective sovereigns.

Panel (a): Changes in sovereign bond yields

	5-year maturity					10-year maturity					20-year maturity				
	Euro Area	Germany	France	Italy	Spain	Euro Area	Germany	France	Italy	Spain	Euro Area	Germany	France	Italy	Spain
1-day change	−0.5056***	−0.0796	−0.2086	−1.0280***	−0.6196**	−0.5201**	−0.3538	−0.5676***	−1.1212***	−0.8138***	−0.4405*	−0.2872	−0.5206**	−0.9082***	−0.8164***
2-day change	−0.9520***	−0.3648*	−0.5931***	−1.3041***	−1.1599***	−1.0396***	−0.6548**	−1.0447***	−1.6167***	−1.3628***	−1.0183***	−0.8158**	−1.0998***	−1.4168***	−1.4219***

Panel (b): Changes in corporate bond yields

	Non-financial corporations, 5–10-year maturity	Financial corporations, 5–10-year maturity
1-day change	−0.3593**	−0.3237**
2-day change	−0.8365***	−0.7707***

Panel (c): Changes in the stock market

EuroStoxx50	Germany	France	Italy	Spain
13.70*	11.58	10.55	21.13**	15.58**

Panel (d): Changes in inflation expectations

5-year inflation	10-year inflation	20-year inflation
0.3370*	0.0588	0.2423

Panel (e): Changes in euro overnight interest swaps

1-year	3-year	5-year
−0.0556	−0.0795	−0.1988

Panel (z): Changes in Euro-exchange rates

USD/EUR	GBP/EUR	CHF/EUR	JPY/EUR	NEER
−11.44***	−7.76**	−1.64	−10.29***	−5.87***

Panel (h): Changes in forward-looking stock market volatility

VSTOXX50	VIX
−18.53**	−8.7837

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 6.2.: Asset price effects around APP announcement dates (controlled event study)

If I further assume that German Bunds represent the benchmark for non-defaultable bonds, then the decrease in German yields should be a combination of the *signaling channel* and the *duration risk channel*. Given that intermediate overnight-index swap rates (calculated as the average of 1 to 5-year OIS rates, cf. Table 6.2, Panel (e)), which I interpret as a proxy for the signaling channel, declined by about 10 basis points, the duration channel measured as the yield difference between two-day changes in 5-year German Bunds and average OIS-rates accounts for approximately $36 - 11 = 25$ basis points of the overall reduction in yields.[9]

Hence, the yield spreads with respect to German Bunds reflect in large parts the country-specific contributions of the *credit risk channel* (see also Altavilla et al., 2015). The corresponding results are depicted in Table 6.3. As expected, the results highlight that the governments of the relatively vulnerable countries (Italy, Spain) benefited the most from the ECB's asset purchase program. Actually, the Italian spread declined between 76 and 96 basis points depending on the maturity. I think this is a plausible result, given the negative outlook for the Italian economy in the medium term.

	5-year maturity				10-year maturity			
	EA	France	Italy	Spain	EA	France	Italy	Spain
$\Delta_{\text{1-day}}$	42.60	19.90	94.84	54	16.63	21.38	76.74	46
$\Delta_{\text{2-day}}$	58.72	22.83	93.93	79.51	38.48	38.99	96.19	70.80

Table 6.3.: Cumulated government bond spreads (in basis points)

Overall, our results suggest that the APP had an economically meaningful impact on yields, despite being implemented during comparatively tranquil times on financial markets. In accordance with these results, the Bundesbank estimates that the downturn in average interest for euro area governments has yielded savings of almost €1 trillion (about 9% of euro area GDP), despite generally increasing public debt ratios since 2008 (Bundesbank, 2017).

Spillover Effects to Other Asset Classes Since I have identified the duration and credit risk channel, which are both sub-channels of the portfolio balance channel, to be the

[9] In an OIS contract, swap partners exchange fixed interest rate payments for variable rate payments over the life of the contract. The variable rate is usually derived from the interbank overnight rate of the OIS currency. Thus, OIS yields reflect market expectations about the future course of the short-term interest rate. At maturity, the swap is settled by computing the difference between fixed rate payments and the average of the variable rate payments on the notional swap principal. Since swap partners only exchange net interest differentials at maturity but no principal, OIS contracts carry neither default nor liquidity risk.

major transmission channels of the APP, I expect it to have significant spillovers also to other asset classes. In general, the mechanism behind the portfolio balance channel can be described as follows: If the central bank purchases a particular security, it reduces the amount of that security in the portfolios of private market participants, while simultaneously increasing the level of reserves. If private portfolios were in equilibrium before the transaction, the central bank has to offer a higher price for the purchased security in order for private investors to be willing to sell it. As a consequence, central bank purchases bid up the price of that particular security and lower its yield. These direct effects of the APP on euro area government bond yields have been illustrated in the previous section.[10]

However, as investors rebalance their portfolios by buying broadly similar assets, the yield effects are transmitted also to securities that are not directly purchased by the central bank. Accordingly, in our controlled event study with two-day windows, I estimate that the APP significantly lowered the yields on BBB euro area non-financial corporate bonds with maturities between 5-10 years by about -84 basis points, while the corresponding yields of euro area financial corporates significantly decreased by -77 basis points (see Table 6.2, Panel (b)).[11] Moreover, the prices of European (EuroStoxx50), Italian (FTSE MIB) and Spain (IBEX35) equities rose significantly due to the APP, while the value of the euro experienced a significant depreciation with respect to the USD and other major currencies (see Panel (c) and (g), respectively). This relatively large spillover effect is consistent with the decline in overall market uncertainty as measured by VSTOXX50 (respectively VIX), because, ceteris paribus, this fosters arbitrage and thereby increases the spillovers to other asset classes (Panel (h)). Finally, the cumulated changes of the inflation swap rates suggest that the APP stabilized medium term inflation expectations, but these results are not statistically significant (Panel (e)).[12] Again, these results lend support to the hypothesis that the portfolio balance channel was the pre-eminent transmission channel for QE in the euro area

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[10] For empirical evidence on the portfolio balance effect in the US, see e.g. Gagnon et al. (2011b); Hamilton and Wu (2012); Joyce and Tong (2012); D'Amico et al. (2012); Greenwood and Vayanos (2014).

[11] It should be noticed, however, that our sample also includes the beginning of the ECB's corporate sector purchase program (CSPP). Therefore, it is hard to disentangle the direct yield effects of the CSPP from the indirect spillover effects. But as the volume of the CSPP is relatively small compared to the purchases of government bonds, it seems plausible that significant spillover effects exist.

[12] In the literature, this is sometimes referred to as the inflation reanchoring channel (Andrade et al., 2016b).

6.3. Robustness Checks

As a first robustness check, I estimate the non-controlled regression model ⟨6.1⟩. While the results, which are displayed in Table 6.4, are qualitatively similar, they are generally smaller than those of our baseline approach. This suggests that not controlling for macroeconomic news would lead to an underestimation of the APP's effectiveness.

As a second robustness check, I vary the set of event dates. First, I include the ECB press conference of December 3th, 2015. In this press conference, the Governing Council announced a series of policy measures.

First, regarding the ECB's key interest rates, the Governing Council decided to lower the interest rate on the deposit facility by 10 basis points to -0.30%, while the rates on the main refinancing operations and the marginal lending facility remained at 0.05% and 0.30% respectively. Second, regarding the APP, the Governing Council announced its decision to extend the APP to March 2017, or beyond, if necessary, "and in any case until the Governing Council sees a sustained adjustment in the path of inflation consistent with its aim of achieving inflation rates below, but close to, 2% over the medium term (ECB, 2015i)." Third, it was decided to reinvest the principal payments on the maturing securities purchased under the APP "for as long as necessary." With these measures, however, the Governing Council disappointed high market expectations for a more accommodative stance, especially after the ECB had for weeks stoked expectations of a major stimulus package (Koranyi and O'Donnell, 2015). As a consequence, including this event decreases the estimated effect of the APP on financial markets (see Table 6.5). Nevertheless, the net impact remains present – particularly for the high risk countries Italy and Spain.

Panel (a): Changes in sovereign bond yields

	5-year maturity					10-year maturity					20-year maturity				
	Euro Area	Germany	France	Italy	Spain	Euro Area	Germany	France	Italy	Spain	Euro Area	Germany	France	Italy	Spain
1-day change	-0.4783^{***}	-0.0595	-0.1936	-0.9911^{***}	-0.5867^{**}	-0.4877^{**}	-0.3227	-0.5355^{**}	-1.0645^{***}	-0.7674^{***}	-0.4038^{*}	-0.2515	-0.4776^{*}	-0.8590^{***}	-0.7575^{**}
2-day change	-0.9202^{***}	-0.3411^{*}	-0.5721^{***}	-1.2587^{***}	-1.1278^{***}	-1.0042^{***}	-0.6190^{**}	-1.0075^{***}	-1.5576^{***}	-1.3147^{***}	-0.9794^{***}	-0.7773^{**}	-1.0542^{***}	-1.3616^{***}	-1.3628^{***}

Panel (b): Changes in corporate bond yields

	Non-financial corporations, 5–10-year maturity	Financial corporations, 5–10-year maturity
1-day change	-0.3401^{**}	-0.3079^{**}
2-day change	-0.8126^{***}	-0.7527^{***}

Panel (c): Changes in the stock market

EuroStoxx50	Germany	France	Italy	Spain
13.89^{*}	11.65^{*}	10.75	21.37^{**}	16.04^{**}

Panel (d): Changes in inflation expectations

5-year inflation	10-year inflation	20-year inflation
0.3249^{*}	0.0720	0.2304

Panel (e): Changes in euro overnight interest swaps

1-year	3-year	5-year
-0.0525	-0.0743	-0.1771

Panel (z): Changes in Euro-exchange rates

USD/EUR	GBP/EUR	CHF/EUR	JPY/EUR	NEER
-11.12^{***}	-8.05^{**}	-1.74	-9.98^{***}	-5.71^{***}

Panel (h): Changes in forward-looking stock market volatility

VSTOXX50	VIX
-19.55^{**}	-9.3681

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 6.4.: Asset price effects around APP announcement dates (uncontrolled event study)

Panel (a): Changes in sovereign bond yields

	5-year maturity					10-year maturity					20-year maturity				
	Euro Area	Germany	France	Italy	Spain	Euro Area	Germany	France	Italy	Spain	Euro Area	Germany	France	Italy	Spain
1-day change	−0.3532**	0.1101	−0.0247	−0.8064***	−0.4230*	−0.3688*	−0.1431	−0.3426	−0.8711***	−0.5656*	−0.3015	−0.1299	−0.3420	−0.6905**	−0.5801*
2-day change	−0.7385***	−0.1161	−0.3766*	−1.0825***	−0.9434***	−0.8221***	−0.4103	−0.7986**	−1.3379***	−1.0870***	−0.8520**	−0.6351*	−0.9149**	−1.2178***	−1.1806***

Panel (b): Changes in corporate bond yields

	Non-financial corporations, 5–10-year maturity	Financial corporations, 5–10-year maturity
1-day change	−0.1888	−0.1724
2-day change	−0.6284***	−0.5841***

Panel (c): Changes in the stock market

EuroStoxx50	Germany	France	Italy	Spain
9.66	7.59	6.54	18.37*	12.86

Panel (d): Changes in inflation expectations

5-year inflation	10-year inflation	20-year inflation
0.2954	0.0360	0.1913

Panel (e): Changes in euro overnight interest swaps

1-year	3-year	5-year
0.0571	0.0625	−0.0040

Panel (z): Changes in Euro-exchange rates

USD/EUR	GBP/EUR	CHF/EUR	JPY/EUR	NEER
−8.6337***	−5.8301*	−1.2899	−7.8102**	−5.2755***

Panel (h): Changes in forward-looking stock market volatility

VSTOXX50	VIX
−18.50**	−6.51

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 6.5.: Asset price effects around APP announcement dates (including Dec 03, 2015, controlled event study)

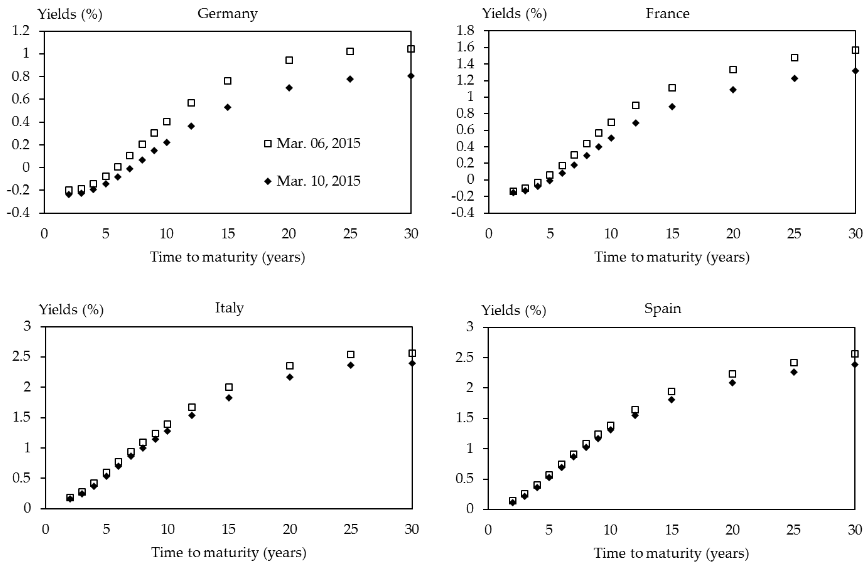

Figure 6.2.: Euro area yield curves at APP implementation date (Mar. 09, 2015) ◇ White squares (black diamonds) depict the closing yields one business day before (after) the implementation date ◇ *Source:* Datastream

In an alternative robustness check, I confine our study to the first official announcement and implementation dates (January 22, 2015 and March 09, 2015). In doing so, I still get sizeable effects on government bond yields, albeit they are substantially smaller than the cumulated effects of my baseline approach. Table 6.6 displays the regression results. The finding of a significant yield effect around the implementation date is striking (see also Figure 6.2), especially since all relevant market information on the APP had been previously released on March 05, 2015 (ECB, 2015e). Concerning the transmission channels, however, it is rather unlikely that the yield effects around the implementation date are evidence for the local supply channel, since no such effects are recorded for the purchases of subsequent days. Instead, Andrade et al. (2016b) argue that the effects recorded around March 09 are due to the diffusion of new information – for instance on the exact maturity distribution of the purchases. Since such information was previously unknown to market participants, this explanation is consistent with the duration channel.

Panel (a): Changes in sovereign bond yields

	5-year maturity					10-year maturity					20-year maturity				
	Euro Area	Germany	France	Italy	Spain	Euro Area	Germany	France	Italy	Spain	Euro Area	Germany	France	Italy	Spain
1-day change	−0.0464	−0.0129	−0.0035	−0.1222*	−0.0357	−0.0200	−0.1527***	−0.1755***	−0.1672**	−0.0932	0.0135	−0.1786***	−0.1854***	−0.2375***	−0.1603**
2-day change	−0.1650***	−0.0808	−0.1161**	−0.1569*	−0.1113	−0.2732***	−0.3114***	−0.3203***	−0.2846***	−0.1983*	−0.3392***	−0.3780***	−0.3768***	−0.4876***	−0.4098***

Panel (b): Changes in corporate bond yields

	Non-financial corporations, 5–10-year maturity	Financial corporations, 5–10-year maturity
1-day change	−0.0868**	−0.0871**
2-day change	−0.1754***	−0.1727***

Panel (c): Changes in the stock market

EuroStoxx50	Germany	France	Italy	Spain
1.39	1.51	0.92	3.15	3.15

Panel (d): Changes in inflation expectations

5-year inflation	10-year inflation	20-year inflation
0.0706	0.0746	0.0547

Panel (e): Changes in euro overnight interest swaps

1-year	3-year	5-year
−0.0140	−0.0166	−0.0459

Panel (z): Changes in Euro-exchange rates

USD/EUR	GBP/EUR	CHF/EUR	JPY/EUR	NEER
−1.5982*	−1.4737*	−1.1247**	−0.9374	−0.3091

Panel (h): Changes in forward-looking stock market volatility

VSTOXX50	VIX
−2.65	−2.37

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 6.6.: Asset price effects around January 22, and March 9, 2015 (controlled event study)

Relation to the Literature In comparison, the econometric results of the present study are somewhat larger than those found by Altavilla et al. (2015). For a one-day window, the latter estimate the APP effect on GDP-weighted euro area 10-year sovereign bonds to be -29 basis points, and -47 basis points in case of a two-day window. The corresponding estimates of the present study are -33 basis points and -74 basis points, respectively. Evidently, this difference results mainly from the larger event set of the study at hand.

In contrast, Andrade et al. (2016a) confine their event study only to the APP's announcement and implementation date (January 22 and March 09, 2015), and to control for QE expectations prior to the announcement, they use survey information from Bloomberg to capture the size shock of the announcement. As they document that prior to the announcement the median expectations for the size of the program were lying at about €550 billion, their scaled estimates imply that eligible 10-year sovereign bonds decreased by -45 basis points. Using a comparable time period in the event study above means that euro area 10-year sovereign bonds declined by -53 basis points.[13] Given the fundamental differences in controlling for pre-announcement effects, the close similarity between both estimates can be seen as positive evidence for the robustness of my results.

The work by De Santis (2016) offers another interesting benchmark. By running a more sophisticated error correction model, which, beyond APP events, accounts for macro risk factors like liquidity risk, credit risk, and systematic risk, De Santis (2016) finds that the APP reduced the GDP-weighted 10-year euro area sovereign yield by 63 basis points. In addition, he also finds that countries with a bad credit outlook (Italy -80 basis points, Spain -75 basis points) experienced a larger drop in yields than countries with a better outlook (Germany, -43 basis points).[14] In conclusion, this means that the econometric results of the present study are broadly in line with the other empirical evidence in the literature.

6.4. Concluding Remarks

Consistent with the predictions from a credit risk augmented preferred-habitat model, I have documented that the ECB's large-scale asset purchase program of euro area go-

[13] The cumulated two-day change for all events from March 25, 2014 until March 09, 2015.

[14] The econometric analysis be De Santis (2016) focuses on a time period between September 2014 and October 2015.

vernment bonds had a substantial effect on financial markets. In particular, my results suggest that the distressed periphery countries benefited more from the APP than the euro area core countries. In this regard, the significant heterogeneity across euro area yields is likely governed by the different degrees of credit risk of the respective sovereigns. In addition, the duration risk channel seems to have played an important role.

Apart from moral hazard issues, my findings therefore suggest that in order to maximize the APP's overall effectiveness, asset purchases in the euro area should be geared towards long duration bonds of the countries with the lowest credit quality. Since, however, moral hazard issues play a key role in the current design of the euro area, it might be a sound decision to keep the national purchase volumes conditional on the ECB's capital key. Moreover, from a legal standpoint, the ECB would get into great difficulties explaining why discretionary bond purchases of distressed sovereigns would not fall into the realm of monetary financing of member states.

Part III.

Macroeconomic Effects of Unconventional Monetary Policies

7. The Credit Channel of Asset Purchase Programs

So far, this analysis – as the vast majority of research on LSAPs in the literature – has focused on the capital market effects of LSAPs, while any effects on the *credit channel* have received much less attention. This downplay of the *credit view* may reflect the fact that policymakers expected LSAPs to work mainly through changes in asset prices, because banks were forced to deleverage in the financial crisis. The following excerpt from the minutes of the Bank of England confirms this assessment:

> "A significant programme of asset purchases was likely to be necessary in order to make up this shortfall in nominal spending. The current strains in the financial system, and in particular the pressure on banks to reduce the size of their balance sheets, meant banks were less likely to increase their lending substantially following an increase in their reserves [...] The Committee noted that [...] asset purchases were likely to be most effective if they were purchased from the domestic non-bank financial sector rather than from banks." (Bank of England, 2009, pp. 9-11)

To check whether this scepticism about the *credit view* is valid I am going to discuss the theoretical foundations and the empirical evidence for the *credit channel* of unconventional monetary policies. As illustrated in Figure 7.1, the *credit channel* is usually split into two sub-channels, the *balance sheet channel* and the *bank lending channel*.

Formally, the microfoundations of the *credit view* hinge on information asymmetries between borrowers and lenders (see inter alia Bernanke and Gertler, 1989; Bolton and Scharfstein, 1990). As a consequence, certain borrowers are unable to tap capital markets but depend on bank loans as the only source of external finance.[1] Thus, financial frictions due to agency costs provide the rationale for the imperfect substitutability between loans and bonds in this class of models. Another corollary of the *credit view* is that ex-

[1] Holmstrom and Tirole (1997) and Bolton and Freixas (2000), for instance, show that insufficient capital can constrain firms' ability to raise funds on capital markets. Alternatively, Diamond (1991) argues that firms lacking a certain reputation (or rating) face difficulties when they try to issue bonds on capital markets.

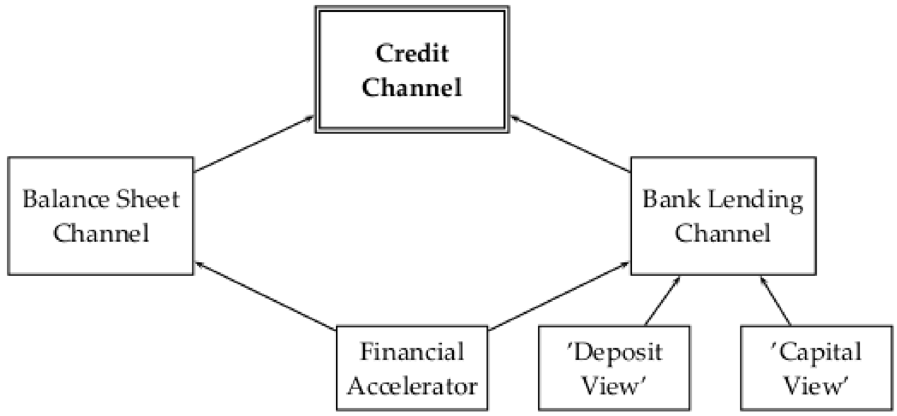

Figure 7.1.: The broad credit channel

ternal finance is more costly than internal finance, which gives rise to an *external finance premium* violating the Modigliani-Miller assumptions (Bernanke and Blinder, 1988).

The *credit view's* emphasis on the importance of bank loans contrasts with the *money view*. In the latter, deposit creation can give rise to liquidity or real balance effects, but since the supply of deposits is supposed to be a stable function of the monetary base, banks do not require much attention concerning the *money view*. In fact, bank loans are pooled together with other debt instruments in a generic bond market – rendering financial intermediation essentially irrelevant. In other words, whilst the implicit assumption of the *money view* is that monetary policy can directly influence the *stock* of (broad) money, the *credit view* deals with the impact of monetary policy on the *flow* of credit.[2] As illustrated in Figure 7.1, the policy-induced effects on the financial strength of bank-dependent borrowers are usually referred to as the *balance sheet channel*, whereas the effects on loan supply are subsumed under the *bank lending channel*. In what follows, I will discuss both channels in more detail.

7.1. Balance Sheet Channel

In principle, loan commitments by a profit maximizing bank should increase with borrowers' willingness to pay higher loan rates. However, Stiglitz and Weiss (1981, 1992)

[2]Trautwein (2000) offers an excellent literature review about the credit channel as well as a thorough comparison with the money view.

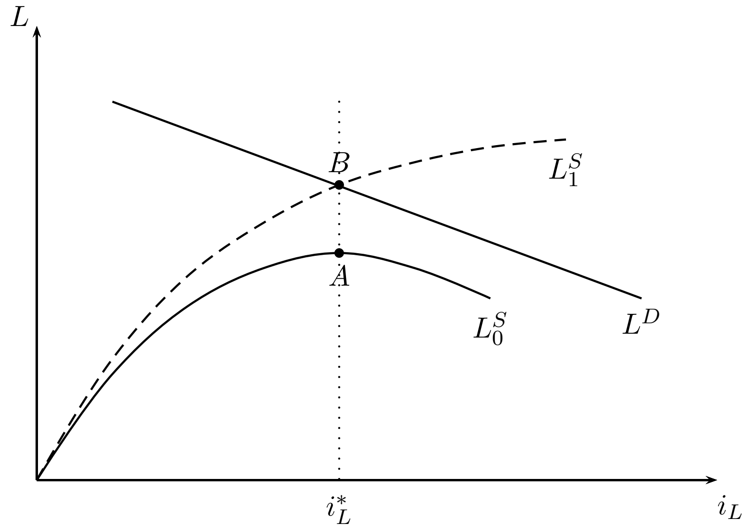

Figure 7.2.: Credit rationing

show that if higher loan rates attract only risky borrowers, information asymmetries can lead to a classical *adverse selection* problem.[3] As illustrated by point A in Figure 7.2, banks' credit supply starts to decrease at a certain level of the loan rate, and the resulting rationing equilibrium [AB] reduces welfare, as it prevents the realization of positive net present value projects (see inter alia Greenwald and Stiglitz, 1986; Hubbard, 1995; Jiménez et al., 2014; Cingano et al., 2016).[4] Yet if banks mitigate the information asymmetries between borrowers and lenders by improving their screening or monitoring techniques, this may lead to an outward shift in the loan supply (L_1^S) for any given level of the loan rate (Diamond, 1984, 1991; Holmstrom and Tirole, 1997).

In general, however, banks can only imperfectly control their borrowers' risk taking incentives. Therefore, banks demand collateral in order to be willing to grant loans. The provision of collateral serves as a discipline device against borrowers' excessive risk taking, because banks can seize the collateral in case of default.[5] The collateral requirements now open up the balance sheet channel of monetary policy, because changes in the policy stance have an inverse impact on the collateral values of potential borro-

[3]Other seminal contributions on the microeconomic consequences of asymmetric information on credit markets include Jaffee and Russell (1976); Townsend (1979); and Gale and Hellwig (1985).

[4]Bester and Hellwig (1987) show that credit rationing can also occur as an ex post phenomenon, namely if borrowers have an incentive to choose a risky investment *after* the loan has been granted. This is the classic *moral hazard* argument.

[5]In a sense, posting collateral helps to internalize the negative externalities emanating from information asymmetries between borrowers and lenders, such that credit rationing can (principally) be avoided (Barro, 1976; Bester, 1985, 1987).

wers.[6] This mechanism, whereupon interest rate changes are *amplified* via the net wealth of borrowers, is usually referred to as the *financial accelerator*.

7.1.1. Simple Model of the Financial Accelerator

The main idea of the financial accelerator and its implications for monetary policy can be illustrated by a static version version of the Bernanke et al. (1996) model.[7] The model considers a firm with equity E that transforms input x into output $f(x)$. For simplicity, input and output prices are normalized to unity. Furthermore, the firm can raise a bank loan L carrying an interest rate i_L. The maximum amount of inputs the firm can afford is thus $x = L + E$.

Money View Firstly consider the case without information asymmetries. In this frictionless benchmark, the optimization problem reads

$$\max_{L} = f(L+E) - (1+i_L)L \tag{7.1}$$

and the first-order condition is

$$f'(L+E) = (1+i_L). \tag{7.2}$$

This frictionless result reflects the *money view*; without information asymmetries, the firm can substitute any decrease in E with an equivalent increase in L, which implies that the *financial accelerator* shuts down completely. As a consequence, the firm's net wealth neither affects investment nor output and the *interest rate channel* suffices to describe the transmission of monetary policy. Optimality requires that an increase in the (gross) loan rate $(1+i_L)$ has to be met by an increase in marginal productivity $f'(L+E)$. Since with diminishing marginal returns of $f(x)$ this can only be achieved by reducing investment in inputs, the optimality condition establishes the conventional inverse relation between interest rates, investment and output.

[6] In this sense, expansionary monetary policy could be another reason for the shift from L_0^S to L_1^S in Figure 7.2.

[7] This simple model is laid out in Freixas and Rochet (2008, ch. 6). Another well-known model that analyzes the importance of collateral constraints for macroeconomic dynamics is Kiyotaki and Moore (1997).

Credit View Next, consider the case when information asymmetries between the firm and its bank requires full collateralization of the loan.[8] With this collateral constraint, the repayment of the loan must be covered by the firm's asset K multiplied by its price q, such that the optimization problem becomes

$$\max_{L} f(L+E) - (1+i_L)L \tag{7.3}$$

$$\text{s.t.} \quad L \leq \frac{qK}{1+i_L}, \tag{7.4}$$

and the first-order condition

$$f'(L+E) = 1 + i_L + \lambda. \tag{7.5}$$

Here, λ denotes the Lagrange multiplier. If the collateral constraint is binding, λ becomes positive, which is tantamount to

$$f'\left(\frac{qK}{1+i_L} + E\right) > (1+i_L). \tag{7.6}$$

Thus, the Langrange multiplier λ represents the *external finance premium* that is critically bound to the collateral value qK; a decrease in qK limits the borrowing capacity of the firm, which leads to an endogenous increase in λ. Thereby, monetary policy affects bank lending, since changes in the policy rate inversely affect the asset price q (not modeled here). Once again, this should illustrate that monetary policy in the *credit view* exerts an influence on investment *beyond* its pure effect on user costs, because interest rate changes are *amplified* by their inverse impact on the net wealth of potential borrowers (the *financial accelerator*).[9]

7.2. Bank Lending Channel

The literature on the bank lending channel basically shifts the focus from borrower's balance sheets to the balance sheet of banks. The key research question in this field is whether monetary policy can significantly affect the supply (or relative price) of bank

[8] Of course, full collateralization is rather uncommon in practice. In this exercise, however, it serves as a benchmark to highlight the basic mechanism of the financial accelerator.

[9] There is extensive literature on the empirical relevance of the financial accelerator. Bernanke et al. (1996) offer a discussion and references.

loans independently of borrower-related channels. A corollary of this argument is that neither borrowers nor lenders should regard loans and bonds as perfect substitutes.

7.2.1. Deposit View

Earlier models of the bank lending channel assumed that monetary policy influenced the supply of bank loans by restricting a bank's access to loanable funds. This was mostly explained by the presence of minimum reserve requirements which enforced a quantitative constraint on bank balance sheets (Bernanke and Blinder, 1988; Kashyap and Stein, 1994, 1995).

Suppose that banks minimum reserve requirements amount to τD. If we apply the same variable classification as above (L_t for loans, B_t for bonds, R_t for reserves, and D_t for deposits), but neglect equity as well as excess reserves, the bank balance sheet equals

$$L_t + B_t + R_t = D_t, \tag{7.7}$$

Since the minimum reserve requirement stipulates that $R_t = \tau D_t$, equation ⟨7.7⟩ can be rearranged to

$$L_t + B_t = (1 - \tau) D_t. \tag{7.8}$$

If monetary policy uses the level of reserves as its policy instrument, a contractionary open market operation results in an overproportionate decline in deposits, since

$$\Delta D_t = \Delta(L_t + B_t) = \frac{1}{\tau}\Delta R_t. \tag{7.9}$$

As shown by the middle term of equation ⟨7.9⟩ – if loans and bonds are imperfect substitutes such that banks cannot just absorb deposit losses by selling bonds – the shortfall of deposits force banks to cut down on their loan supply. Since this tightens the credit conditions of bank-dependent borrowers, the reduction of economic activity is consequently stronger than the one implied by a mere increase in capital market rates. In this way, the *bank lending channel* acts as an *additional amplifier* that works through the supply side of the loan market.

Critique of the Deposit View Given the profound institutional and regulatory changes since the 1980s, the deposit view on the bank lending channel has been increasingly criticized. For example, Romer and Romer (1990) argue that policy-induced reductions in deposits must not entail any adjustment in loan supply, because banks could simply substitute reserveable deposits with other, non-reservable sources of funding (such as certificates of deposits, for instance). Thus, the Romer-Romer critique is based on a Modigliani-Miller type of argument that assumes frictionless markets for banks' wholesale funding.

However, a valid refutation against the Modigliani-Miller argument is that wholesale financing is typically not covered by deposit insurance, such that any bank that borrows on wholesale markets is subject to the same agency problems that restrict households and firms. Hence, the perfect substitutability between reserveable deposit and non-reserveable wholesale financing has been called into question. Stein (1998), for instance, provides evidence that the Modigliani-Miller logic underlying the Romer-Romer critique fails to hold if there is asymmetric information concerning the value of a bank's assets. On the individual bank level, it has been shown that small, less liquid or weakly capitalized banks are particularly responsive to monetary policy shocks, which is seen as positive evidence for the *bank lending channel*.[10]

Notwithstanding this dispute about the Romer-Romer critique, there are more fundamental objections against this *deposit view* on the bank lending channel.[11] Most importantly, modern central banks do not use the quantity of reserves as a monetary policy tool. Instead, they set the price of reserves and let its supply adjust endogenously. From a macro perspective, the notion that financial intermediation is constrained by an exogenous amount of *loanable funds* thus seems to be misguided (Jakab and Kumhof, 2015). Indeed, precisely the opposite seems to be true. Banks *create* deposits by extending credit to households and firms, while the central bank satisfies any potentially arising reserve needs along a perfectly elastic supply schedule (Disyatat, 2008). A corollary of this argument is that the money multiplier logic underlying the deposit view of the bank lending channel is essentially reversed.

Under these circumstances the bank lending channel boils down to a price-theoretic argument in bank funding markets. If the policy rate is raised above the rate on bank deposits, a bank with refinancing needs will try to attract deposits from other banks by marginally increasing its deposit rate. Competition amongst banks will thus bid up the

[10]The size argument is put forward by Kashyap and Stein (1995); liquidity by Kashyap and Stein (2000), whereas capital is emphasized by Peek and Rosengren (1995) and Van den Heuvel (2002), among others.

[11]Since restrictive monetary policy also weakens the collateral values of potential borrowers, a reduction in loan supply is also consistent with the operation of the balance sheet channel. As a consequence, it turned out to be extremely difficult to empirically separate the bank lending channel from the balance sheet channel, which further contributed to the dispute about its effectiveness (Oliner and Rudebusch, 1995; Bernanke and Gertler, 1995).

average deposit rate until it reaches the level of the policy rate. Since, however, banks' maturity transformation implies a relatively sticky return on existing loans, rising refinancing costs result in a profit squeeze for banks. The sole option to restore profitability is thus to substantially raise the rates on *new* lending, which is, however, bound to produce a persistent decline in the volume of credit (Spahn, 2014). Consistent with this argument, Ehrmann et al. (2003) show that in the euro zone, variations in refinancing costs have a stronger effect on bank profitability than in the US, since euro area banks hold a larger fraction of fixed rate long-term loans relative to US banks.[12]

7.2.2. Capital View

As quantitative *reserve* constraints have ceased to limit the supply of bank loans in modern economies, *capital* remains the key quantitative constraint for bank lending (Peek and Rosengren, 1995; Kishan and Opiela, 2000). In fact, this could be either due to regulatory requirements (Adrian and Shin, 2014), or because of asymmetric information on bank funding markets (Bernanke, 2007; Gertler and Kiyotaki, 2011). If a bank lender knows that the capital ratio of the bank determines its own stake and therefore its incentive to monitor borrowers, a higher capital ratio improves the bank's access to external funding sources. In other words, since banks themselves act as borrowers, the logic of the *financial accelerator* applies equally well to them. For banks, however, this mechanism is called the *bank capital channel* (Bernanke and Lown, 1991; Van den Heuvel, 2002, 2006).

To see the role of monetary policy in this context, consider the case of a monetary tightening. Firstly, as banks are exposed to interest rate risks, rising policy rates reduce bank profits. Unless banks can substantially rise the rates on new loans (or lower their dividend payments), their capital will eventually be lower. Secondly, under mark-to-market accounting, rising policy rates cause an adverse valuation effect that directly increases banks' leverage ratios. Thirdly, if tighter monetary policy causes the default rates on bank loans to go up, risk-sensitive capital requirements have to go up as well. Finally, notice also that there is a potential feedback loop between the traditional *bank lending channel* and the *bank capital channel*. If wholesale funding has to pay a "lemon premium" because it is not covered by deposit insurance, those costs should be higher for banks

[12] It should be noted, however, that even prior to the crisis there has been a large heterogeneity in the policy pass-through to lending rates in the euro zone (see e.g. Mojon, 2000 or Kok and Werner, 2006). A plausible factor could be that the ratio between fixed and variable rate loans varies substantially between the members of the euro zone.

with low capital ratios. Put differently, the level of capital can serve as a signal of banks' creditworthiness. Banks with high capital ratios are thus less exposed to asymmetric information problems, which makes such banks more immune to policy induced funding shocks (Jayaratne and Morgan, 2000). In line with this, Jiménez et al. (2012) find that a lower overnight interest rate induces lowly capitalized banks to grant more loans to riskier firms, while Jiménez et al. (2012) document that for distressed commercial banks, a tighter policy stance and worse economic conditions reduce lending substantially.

To sum up, the key characteristic of the *bank capital channel* is that monetary policy affects bank lending through its effect on bank equity. In this way, the *bank capital channel* acts as another amplifier to the standard interest rate channel.

7.2.3. Securitization and Bank Lending

Prior to the financial crisis, the dramatic growth in securitization activities that started in the late 1990s suggests that the effectiveness of the bank lending channel has generally decreased (see inter alia Ehrmann et al., 2003; Angeloni et al., 2003; Altunbas et al., 2004). Firstly, since securitization allows banks to bundle together illiquid loans into tradable

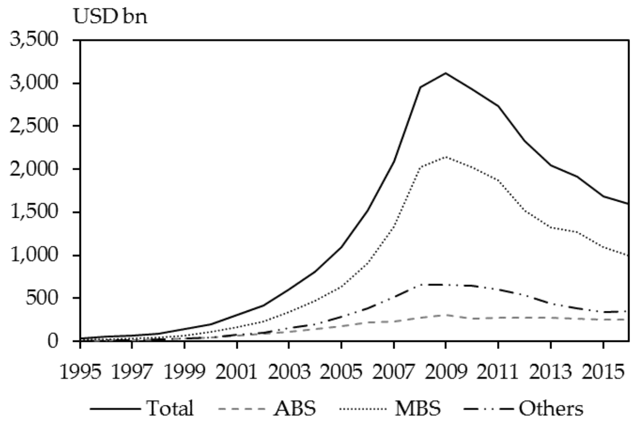

Figure 7.3.: Europe securitization outstanding ◇ 'Others' include CDOs (Credit Default Obligations), SMEs (Small- and Medium-sized Enterprises), WBS (Whole Business Securitization) ◇ European securities are defined as securitizations with collateral predominantly from the European continent, including Turkey, Kazakhstan, the Russian Federation, and Iceland. ◇ *Source:* AFME/SIFMA Members, Bloomberg, Dealogic, Thomson Reuters, prospectus filings, Fitch Ratings, Moody's, S&P, AFME, SIFMA.

securities, it increases banks' liquidity ratios. Secondly, securitization enables banks to remove credit risk from their balance sheet, which entails a regulatory capital relief and a positive net effect on loan supply (Altunbas et al., 2009). In this way, securitization and a broader access to market-based funding sources helped banks to shield their loan supply from monetary policy shocks (Angeloni et al., 2003; Ashcraft, 2006).[13]

But with the outbreak of the financial crisis, securitization and interbank liquidity markets experienced a drastic decline (see e.g. Heider et al., 2015; Frutos et al., 2016). As unsecured holders of commercial paper refused to roll over their debt, while repo lenders required more collateral to back up their loans, there was a run on liquidity that led to a sudden decline in wholesale funding (Brunnermeier and Pederson, 2009).[14] Unlike traditional bank-runs, which were triggered by uninsured depositors, this time it was caused by short-term creditors and counterparties in interbank markets (Gorton and Metrick, 2009).

In line with this development, Ivashina and Scharfstein (2010) document that *new* lending in the US contracted substantially after the failure of Lehman Brothers.[15] And while this reduction in lending could simply reflect a drop in credit demand, they show that a substantial part was driven by supply effects. In particular, they find that bank-specific characteristics did play a large role in the credit squeeze: banks that were heavily reliant on short-term debt cut their lending by more than did banks with better access to stable deposit funding. For Europe, this finding is confirmed by the study of Gambacorta and Marques-Ibanez (2011), who demonstrate that banks with weaker core capital positions and greater dependence on market funding experienced a sharper decline in lending. Moreover, they find that banks' business models had a significant impact on their supply of credit. In particular, banks that were heavily involved in securitization and non-interest income activities (e.g. investment banks) limited their loan supply to a greater extent.

[13]Note that this observation essentially underscores the Romer and Romer (1990) critique. In contrast, however, Jiménez et al. (2012) argue that empirical studies that rely on bank level data using only credit aggregates (such as Angeloni et al., 2003; Ashcraft, 2006) systematically underestimate the bank lending channel, because these studies are unable to capture the strong correlation between firm loan demand and the balance sheet strength of banks. Thus, by analyzing a data set which includes information on loan level application with granted loans, they find a significant bank lending channel.

[14]Noteworthy, this pattern also holds for more historical time-series. Jorda et al. (2017) document that before a financial crisis, banks are financing their balance sheets increasingly with non-deposit wholesale financing, while they increasingly turn to deposits as a source of funds after a crisis.

[15]Interestingly, the immediate increase in credit volumes right after Lehman mainly reflected drawdowns of existing credit lines.

7.2.4. A Bank Lending Model of QE

The crisis experience of collapsing interbank markets spurred the interest in the effects of QE on bank lending. In this respect, remember from section 5.1.3 that LSAPs from non-banks exert a dual liquidity effect on bank balance sheets. Firstly, they lead to an increase in reserve holdings. Secondly, they cause an increase in deposits (see Figure 5.11 for a graphical representation). Besides these direct effects, those measures should also improve the bank's capital position, if asset purchases increase the mark-to-market value of bank assets.[16] It thus seems plausible that the policy-induced improvements in banks' liquidity and capital ratios could have helped banks to expand – or at least avoid contracting – their loan supply. To illustrate these possible effects via deposits and bank capital, I will use a slightly modified version of the two-period, partial equilibrium model of Kashyap and Stein (1995).[17]

Suppose banks hold on their asset side illiquid loans (L), liquid short-term bonds (B_S) and reserves (R), but no long-term bonds.[18] Their liabilities consist of equity (E), deposits (D), and non-deposit wholesale liabilities (WL). Hence, the representative bank balance sheet reads

$$L_t + B_{t,S} + R_t = E_t + D_t + WL_t. \qquad \langle 7.10 \rangle$$

Suppose further that the short-term policy rate is at its zero lower bound. Since this implies that short-term bonds and reserves become perfect substitutes, they can be combined to the variable $S_t = B_{t,S} + R_t$, which denotes perfectly liquid 'short-term securities'. The above balance sheet identity can thus be written as

$$L_t + S_t = E_t + D_t + WL_t. \qquad \langle 7.11 \rangle$$

Another corollary of the zero lower bound is that the rate on deposits is zero, too. Since loans cannot be liquidated in period 2, they have to pay a positive premium over S and D, such that the return on loans (i_L) is effectively a spread that captures the bank lending channel by measuring the monetary policy impact on bank returns.

[16]This mechanism in which central bank asset purchases redistribute net wealth towards financial intermediaries has recently been referred to as *stealth recapitalization* (Brunnermeier et al., 2012; Brunnermeier and Sannikov, 2014a).

[17]See Joyce and Spaltro (2014) and Butt et al. (2015) for similar approaches.

[18]The exclusion of long-term bonds is meant to highlight the mechanism behind the bank lending channel. As will be further discussed below, if banks only increase their bond holdings in response to monetary policy shocks, then the bank lending channel shuts down.

The deposit view on the bank lending channel is based on the assumption that monetary policy influences bank lending by variations in the supply of reserves that have a direct impact on aggregate deposits. It was argued above that nowadays this deposit view has to be largely rejected, since reserves are endogenously created under conventional monetary policy regimes. In this section, however, the focus rests on the effects of *unconventional* asset purchases which are implemented at the zero lower bound of the short-term policy rate. In particular, it is assumed that assets are only purchased from non-banks. Although this assumption is of course highly stylized, it ensures that LSAPs lead to a one-on-one increase in deposits. In other words, at least for unconventional asset purchases from non-banks, it seems justified to interpret monetary policy as an exogenous shock to deposits. Since the main interest lies in the reaction of bank loans, I simply consider an expansionary monetary policy shock (ϵ_0^M) as higher than average deposits in period 0, i.e.

$$D_0 = \bar{D} + \epsilon_0^M. \qquad \langle 7.12 \rangle$$

Once the monetary policy shock is realized in period 0, there might be a payment shock in period 1 that that either adds or withdraws deposits from banks. Deposits in period 1 are thus given by

$$\rho D_0 + (1-\rho)\bar{D} + \epsilon_1^P \qquad \langle 7.13 \rangle$$

where ρ measures the persistence of deposits and $\epsilon_1^P \sim N(0, \sigma^2)$ represents the payment shock.

Importantly, if banks suffer from a shock to deposits, they can refinance the shortfall by issuing non-deposit liabilities in both periods, while the level of loans is only determined in period 0. Hence, WL_0 denotes the amount of non-deposit liabilities issued after the shock in period 0 (but before the shock in period 1), while WL_1 denotes the amount issued after the realization of the shock in period 1. Very importantly, the key assumption of the model is that non-deposit financing is subject to increasing marginal costs given by

$$\frac{\alpha_0 (WL_0)^2}{2} \quad \text{and} \quad \frac{\alpha_1 (WL_1)^2}{2}, \qquad \langle 7.14 \rangle$$

respectively. If $\alpha_0 = \alpha_1 = 0$, banks can raise external finance at a perfectly-elastic supply schedule, implying that the bank lending channel shuts down completely. For $\alpha_1 > \alpha_0 > 0$, however, these quadratic-cost terms reflect a generic version of the capital market imperfections that explain a refutation of the Modigliani-Miller propositions. Thus, there are two possible scenarios after the realization of deposit shock in period 1:

Either

$$WL_0 + D_1 + E_0 > L, \tag{7.15}$$

or

$$WL_0 + D_1 + E_0 < L. \tag{7.16}$$

In the first case, the bank's funding constraint is non-binding such that it does not need to cut down lending. In the second case, however, even after drawing down all of its liquid securities (S), the bank is still short of funds. Therefore, it needs to issue external funds (WL) to make up the shortage of funds. The net amount of wholesale liabilities issued after the deposit shock in period 1 is thus

$$WL_1 = \max(0,\ L - WL_0 - D_1 - E_0) \tag{7.17}$$

with the expected costs

$$\frac{\alpha_1}{2}E(WL_1)^2 = \frac{\alpha_1}{2}E(\max(0,\ L - WL_0 - D_1 - E_0))^2. \tag{7.18}$$

Since a bank takes recourse to non-deposit wholesale finance only for adverse shocks to deposits, D_1 in the above equation can be substituted with the lower bound of equation ⟨7.13⟩. Furthermore, as the second moment of a uniform distribution over $[a,\ b]$ equals $E(X^2) = \frac{a^2+b^2+ab}{3}$, while in this case we have $a = 0$ and $b = L - WL_0 - D_1 - E_0$, it follows that

$$\frac{\alpha_1}{2}E(WL_1)^2 = \frac{\alpha_1}{6}\left(L - WL_0 - \rho D_0 - (1-\rho)\bar{D} + \frac{\sigma^2}{2} - E_0\right)^2 \tag{7.19}$$

With deposits carrying zero interest, bank profits Π are generated from loans minus the costs of wholesale finance, i.e.

$$\Pi = rL - \frac{\alpha_0(WL_0)^2}{2} - \frac{\alpha_1 E(WL_1)^2}{2} \tag{7.20}$$

As derived in the Appendix B.5, banks optimal loan supply follows

$$L = \frac{3}{\alpha_1}r + \frac{r}{\alpha_0} + \rho D_0 + (1-\rho)\bar{D} - \frac{\sigma^2}{2} + E_0. \tag{7.21}$$

This loan supply function suggests that an increase in deposits due to LSAPs from non-banks leads to an increase in bank lending. Moreover, it also highlights the potential of the *bank capital channel*. A higher value of bank equity E has a positive effect on bank lending, while higher agency costs (i.e. higher values of α_1 and α_2) dampen the effect.

Assuming n banks and a simple loan demand function of the form

$$L^D = Y - kr, \tag{7.22}$$

market clearing in the loan market requires that

$$Y - kr \stackrel{!}{=} nL, \tag{7.23}$$

which can be rearranged to get the equilibrium loan market rate, r, as

$$r = \frac{1}{\frac{3n}{\alpha_1} + \frac{n}{\alpha_0} + k}\left(Y - n\left(\rho D_0 + (1-\rho)\bar{D} - \frac{\sigma^2}{2} + E_0\right)\right). \tag{7.24}$$

Finally, this expression can be differentiated with respect to D_0 to get

$$\frac{\partial r}{\partial D_0} = \frac{1}{\frac{3n}{\alpha_1} + \frac{n}{\alpha_0} + k}\left(\frac{\partial Y}{\partial D_0} - n\rho\right) \tag{7.25}$$

which means that a bank lending channel of QE exists if

$$\frac{\partial r}{\partial D_0} < 0. \tag{7.26}$$

As can be inferred from equation ⟨7.25⟩, this is only the case if variations in deposits have a small impact on aggregate demand, because otherwise a rise in loan demand would prevent a fall in the loan rate. Moreover, equations ⟨7.24⟩ and ⟨7.25⟩ show that the interest rate response to a deposit shock increases with the costs of non-deposit wholesale financing, since both equations increase in α_0 and α_1.

Lastly, it should be noted that the model in this section is of course highly stylized. It abstracts from the behavior of non-banks and models monetary policy only as exogenous shocks to deposits. In particular, if assets are purchased from non-banks, banks are not only granted an inflow of deposits, but they also experience an increase in reserve holdings (see Figure 5.11). Now, in reality, the effectiveness of the bank lending channel depends critically on the banking sector's reaction to these improvements in their liquidity and funding conditions. Only if banks use some of the additional liquidity to increase their loan supply will LSAPs exert a positive impact on bank lending.

7.3. Empirical Evidence for the Credit Channel

7.3.1. Evidence for the UK

Contrary to the usual presumption of the bank lending channel, Butt et al. (2015) argue that the instantaneous increase in deposits due to QE did not act as a stable funding source for banks. Instead, they show that portfolio rebalancing by non-banks led to an increase in the velocity of deposits within the banking sector. As a consequence, the presumably tight link between reserves, (broad) money, and lending collapsed when the Bank of England started to massively increase its reserve supply (see Figure 7.4).

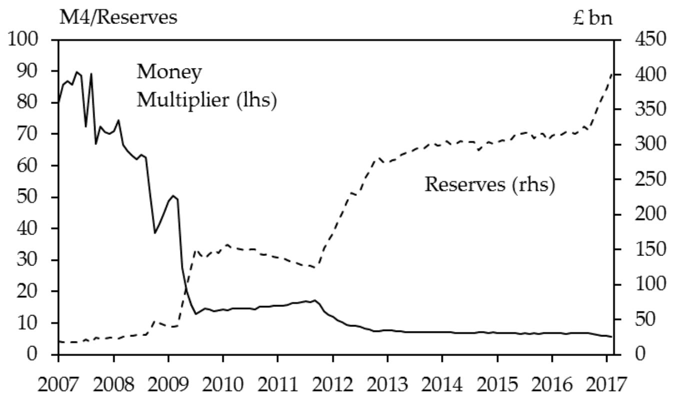

Figure 7.4.: UK money multiplier (lhs) and monthly average of outstanding reserves (rhs) ◇ *Source:* Bank of England

In the above model, this mechanism can be explained by both the persistence parameter ρ, and the variance of the payment shock σ^2; a lower ρ and a higher σ^2 increase the 'flightiness' of deposits relative to the baseline case. Therefore, individual banks may decrease their loan supply, because the expected costs of wholesale financing increase when deposits are likely to quickly leave the bank (see equations $\langle 7.19 \rangle$ and $\langle 7.21 \rangle$, respectively).

However, this argument might be subject to a fallacy of composition. Ultimately, asset purchases from non-banks cause an *aggregate* increase in deposits.[19] Therefore, even if an *individual* bank is experiencing an outflow of deposits, it should either expect a subsequent inflow of deposits, or it should know that another bank will have excess deposits which it will lend out on the interbank market. In either case, even though

[19] As outlined above, for this condition to hold, money demand must remain constant.

deposits may be quickly moving from one bank to another, *aggregate funding conditions* will be improved, which should increase bank lending.

During a financial crisis, however, there are at least two compelling arguments against this presumption. Firstly, if banks' liquidity preference rises, a bank facing a shortfall of deposits might find it increasingly difficult to borrow on the interbank market. Since the tighter conditions on interbank markets involve higher expected costs of wholesale funding, precautionary motives mitigate the probability that a bank would lend out funds if it received 'flighty' deposits. A second reason why QE might have failed to stimulate bank lending via deposit creation is that banks raised new capital (or issued long-term debt), which effectively drained deposits from the system (see Bridges and Thomas, 2012 and Butt et al., 2012 for estimates of this effect).

Against this background, most empirical papers for the UK cannot identify a material impact of QE on bank lending in the UK (Goodhart and Ashworth, 2012; Butt et al., 2015). Figure 7.5, which depicts an average annual loan growth of only 1.5% for the period 2008-2017, generally supports this conjecture. However, simply looking on loan

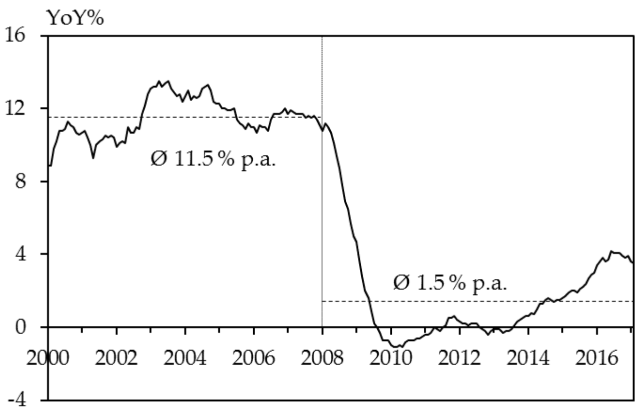

Figure 7.5.: UK bank lending to the private sector ⋄ Adjusted for loan sales and securitization ⋄ *Source:* Bank of England, Datastream.

growth as evidence for the bank lending channel is problematic, as it confuses supply and demand effects. Therefore, Joyce and Spaltro (2014) tackle this problem by showing that QE has different effects on bank lending depending on a number of bank-specific characteristics. Since such differences between banks in response to a monetary policy shock can hardly be explained by changes in the demand for credit, they indicate a reaction of the supply side consistent with the bank lending channel. In particular, Joyce and Spaltro (2014) show that lending by small banks is more responsive to changes in deposits.[20] Furthermore, they find positive evidence that bank lending is positively related to banks' capital ratio, suggesting that the effect of QE on bank lending might have been mitigated by the low level of capital during the crisis. Overall, these observations justify the BoE's intention to circumvent the banking sector. Moreover, they suggest that the impact of QE on bank lending could have been amplified if policymakers had accompanied asset purchases with direct equity injections into banks (He and Krishnamurthy, 2013).

7.3.2. Evidence for the Euro Area

In contrast to the Bank of England whose unconventional measures mainly aimed at re-activating private financial market activity, the ECB's program of "enhanced credit support" was predominantly geared towards the malfunctioning European banking sector. The reason for the different response in part reflects the bank-based structure of corporate financing in the euro zone compared to US or UK standards (see Figure 7.6). Domestic bank credit as a percentage of non-financial corporations' total debt in the US and the UK equals 29 percent, respectively 33 percent, while it accounts for over 42 percent in the euro area.[21]

Given this relative importance of bank credit financing, the ECB had arguably little alternative to work through the banking system. For the ECB's money market operations, the majority view is that they had a positive impact on bank lending by reducing the crisis-elevated interest rate spreads. For instance, using a Bayesian VAR to estimate the effects of the ECB's policy measures between November 2008 and August 2009, Lenza et al. (2010) find that they had a substantial positive effect on euro area bank lending (even though this positive impact was not strong enough to counteract a substantial contraction in total credit supply, cf. Figure 7.7).[22] In particular, the authors estimate a peak positive impact on loans to households of about 1.5 percentage points, and a maximum effect on corporate loans of about 3 percentage points (relative to a no-policy scenario). They conclude that the non-standard policy measures played a quantitatively

[20] Notice that this size effect is in accordance with the model of section 7.2.4, if we assume that α in equation $\langle 7.14 \rangle$ is higher for smaller banks.

[21] Figure 7.6 also reveals a strong heterogeneity among euro area countries. While domestic bank credit for Greek NFCs represents about 83 percent of total debt, it matters considerably less for French NFCs (39 percent). Following an IMF classification, if bank credit accounts for more (less) than 50 percent of total debt, bank credit is perceived to have a high (low) importance for the respective jurisdiction (IMF, 2012; Bundesbank, 2014).

[22] The respective BVAR model for the euro area was developed by Giannone et al. (2012).

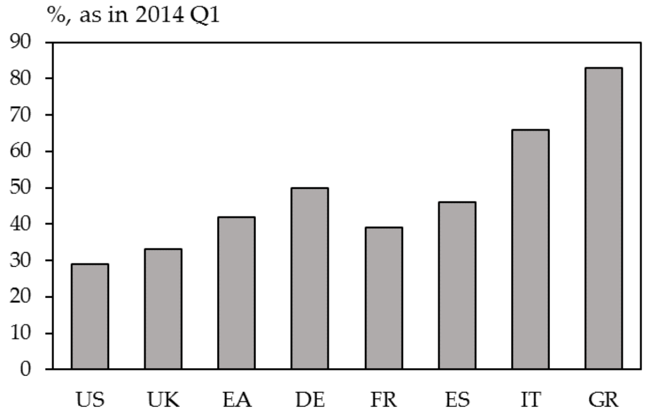

Figure 7.6.: Domestic bank credit as a percentage of NFCs' total debt ◇ Bank credit consists only of loans ◇ *Source:* BIS, Eurostat, ECB, Federal Reserve Board and Bundesbank calculations.

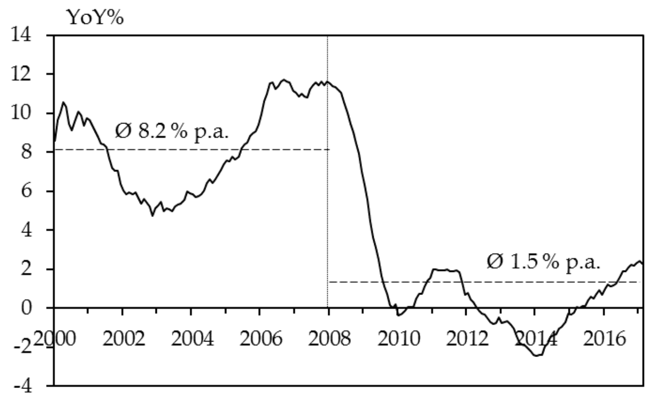

Figure 7.7.: Euro area bank lending to the private sector ◇ Adjusted for loan sales and securitization ◇ *Source:* ECB, Datastream.

significant role in stabilizing the financial sector and the macroeconomic activity after the bankruptcy of Lehman brothers, even if they were insufficient to avoid the serious fall in output, inflation and bank lending to the private sector (Figure 7.7).

The average loan growth of Figure 7.7 shows that loan developments began to stabilize in the course of 2013, but conceals considerable country-specific differences between euro area member countries. As displayed in Figure 7.8, Italian and Spanish lending rates for new business investment did not fall until 2014, while German and French rates were beginning to decline already at the end of 2011. On the credit supply side, availa-

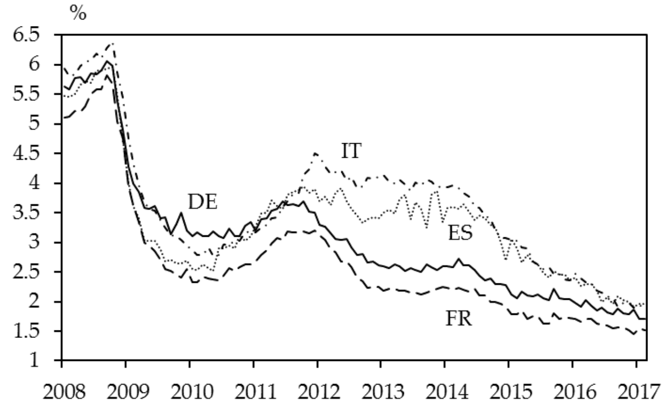

Figure 7.8.: Average interest rates on corporate loans in euro area countries ◇ Time-series are based on the ECB's composite cost of borrowing for new business ◇ *Source:* ECB, Datastream

ble indicators suggest that bank-specific characteristics – especially a high ratio of non-performing loans – were dragging on bank profits and capital levels across the Italian and Spanish banking system.[23] As a result, Italian and Spanish banks increased their lending mark-up to counter their earnings problems despite considerable monetary easing. On the demand side, the weak dynamics of Italian and particularly Spanish loan markets seem to be driven by the need of the non-financial corporate sector to reduce debt-overhangs built up before the crisis (Bundesbank, 2015b). While those factors dampened loan dynamics in periphery countries especially during the years of the sovereign debt crisis, their influence seems to abate recently.

An alternative approach to comprehend the effects of unconventional monetary policies on bank lending uses the monetary base as an empirical indicator. For a sample period between 1999-2009, Peersman (2011) finds that the bank lending declines persistently in response to an expansion of the ECB's balance sheet. In particular, a 10 percent increase in the monetary base is estimated to have the same effect as a 25 basis point cut in the short-term policy rate. Furthermore, the results of Peersman (2011) indicate that when banks' wholesale funding conditions deteriorated in the course of 2008, their

[23]By mid-2016, NPLs net of provisions on Italian banks' balance sheets amount to €191 billion (about 11 percent of GDP). Although the moderate economic recovery since 2014 has contributed to the stabilization of NPLs, further robust economic growth is needed to reduce this stock to a sustainable level. In a recent study, the IMF estimates that the Italian economy has to grow at an annual rate of at least 1.2 percent in order to grow out of its NPL overhang (Mohaddes et al., 2017). However, given that the Italian economy grew above 1.2 percent only in 3 out of the last 10 years, the reality of this scenario seems questionable.

capacity to issue loans for a given amount of central bank money declined. This lends support to the hypothesis that the expansion of central bank funding during the financial crisis had a positive impact on bank lending in the euro area. The papers by Gambacorta and Marques-Ibanez (2011); Hachula et al. (2016); or Carpinelli and Crosignani (2017) generally support this conjecture.

Unfortunately, the above cited studies suffer from a number of caveats: first and foremost, they all use the outstanding *credit stock* – or the change thereof – as the bank lending indicator. As this measure, besides new lending, also includes maturing loans, repayments and write-offs, it may distort the estimates of the credit channel.[24] Secondly, the innovations in the monetary base could be demand-determined, which contradicts the traditional interpretation of the bank lending channel. As a consequence, Behrendt (2017) estimates a structural VAR in the spirit of Peersman (2011), but adopts a credit indicator based on *newly* issued loans. Furthermore, instead of the monetary base, he applies changes in excess reserve as a proxy for unconventional monetary policies. Using these variables, Behrendt (2017) has to reject the hypothesis that unconventional monetary policies had a significant impact on euro area bank lending. Importantly, however, it must be noticed that empirical contributions that employ innovations in central bank balance sheets, by construction, only capture the *implementation*, but not the *announcement* effects of unconventional monetary policies. Thereby, such studies risk to underestimate the true impact of unconventional policies.

Albertazzi et al. (2016) avoid this problem by using as an indicator for unconventional policy the spread between the so-called *shadow rate* and the MRO rate. The shadow rate is a statistical device to describe the stance of monetary policy when the short-term policy rate is close to zero.[25] Since the shadow rate can stay in negative territory even if the policy rate is constrained by the zero lower bound (ZLB), it provides a measure of the expansionary effects of unconventional policies that would prevail in the absence of the ZLB. Moreover, since the shadow rate also summarizes the information about the monetary policy stance included in the term structure of interest rates (Pericoli and Taboga, 2015), it captures both the announcements *and* implementation effects of unconventional policies.

Using a dataset for euro area bank-level interest rates on *new* loans for a period bet-

[24] Behrendt (2016) offers a discussion on the issues involved with the use of credit stock measures in empirical studies on the bank lending channel.

[25] The shadow rate concept for unconventional monetary policies was developed by Krippner (2013a,b).

ween 2007-2015,[26] Albertazzi et al. (2016) thus document that the effect on bank lending differed between conventional and unconventional policy shocks. For conventional policy shocks, they find that the effect on bank lending declines for better capitalized and more liquid banks, which confirms the results of the older bank lending literature, emphasizing the importance of asymmetric information issues. For unconventional policies, however, the bank lending channel is *stronger* for *better capitalized* and *more liquid* banks. Whilst this result seemingly contradicts the older bank lending literature, it supports the notion that regulatory and economic constraints are the key determinants of bank lending in times of crisis (see also Gambacorta and Marques-Ibanez, 2011). In particular, Albertazzi et al. (2016) estimate that the Eurosystem's unconventional policies caused the average loan rate to non-financial corporations to be about 40 basis points lower relative to a no-policy scenario. Moreover, they find that unconventional policies, by flattening the yield curve, exert an adverse effect on bank profitability, which tends to attenuate the monetary policy transmission (*reverse bank capital channel*).[27]

On the other hand, lower interest rates also lead to valuation gains on bank balance sheets (*bank capital channel*). Since the latter should be stronger for banks with large holdings of distressed domestic government bonds, it seems that asset purchases of government bonds (OMT and PSPP) had a positive impact on bank lending, as they addressed potential mispricing in euro area sovereign debt markets (see also Cova and Ferrero, 2015 and Altavilla et al., 2016). Given the multitude of unconventional measures, however, empirical studies increasingly encounter identification problems, especially for the more recent measures. Consequently, time series estimates of contemporary measures (CSPP, PSPP, TLTROs) increasingly run the risk of being distorted by previous operations (e.g. 3y LTROs, SMT, OMT, CBPP1/2).

7.3.2.1. Euro Area Bank Lending Survey (BLS)

Luckily, however, the Eurosystem in its April 2015 bank lending survey (BLS) started to include three *ad hoc questions* to gauge the impact of the ECB's expanded asset

[26] Controlling for credit demand by using country-specific fixed effects and comparing the effects of monetary shocks for banks with different balance sheet characteristics (size, liquidity, capital) allows Albertazzi et al. (2016) to disentangle credit demand from credit supply effects.

[27] Brunnermeier and Koby (2016) provide a thorough discussion of the dynamic negative effects of low net interest margins for bank profitability. Their concept of the so-called *reversal rate* suggests that at some point the level of interest rates can become so low that the detrimental effects on bank profitability outweigh the beneficial effects of lower rates. Interestingly, this concept has been acknowledged by Benoît Coeuré, a member of the Executive Board of the ECB, as being a potential constraint at which further rate cuts risk reversing the expansionary monetary policy stance (Coeuré, 2016).

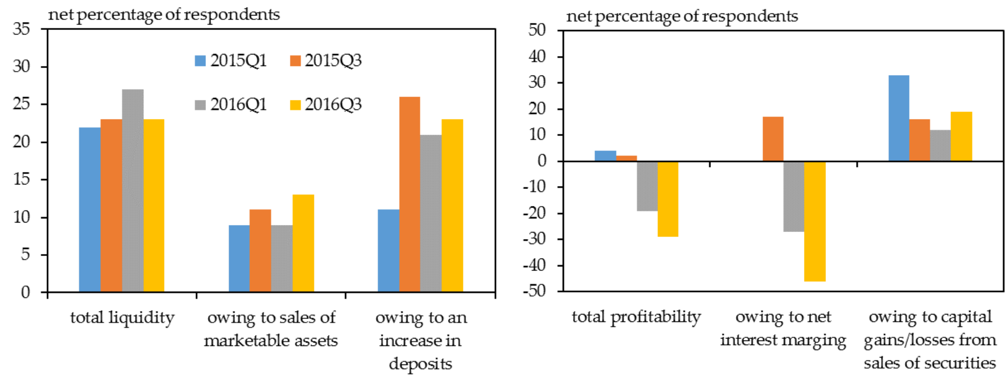

Figure 7.9.: Impact of the APP on euro area banks' financial situation ⋄ *Note:* Net percentages are defined as the the difference between the sum of the percentages of banks responding "increased/improved considerably" and "increased/improved somewhat" and the sum of the percentages of banks responding "decreased/deteriorated considerably" and "decreased/deteriorated somewhat" ⋄ *Source:* Data obtained from the respective bank lending surveys (ECB, 2015b,c, 2016a,b)

purchase program (APP). The APP encompassed the ongoing purchase programs for asset-backed securities (ABSPP) and covered bonds (CBPP3), but was extended to include asset purchases of European public sector bonds (PSPP).[28] Since then, banks in the euro area are asked every six months to report the impact of the APP on their financial situation. Furthermore, they shall report the purposes for which they used the additional liquidity arising from the APP and provide an assessment on their lending conditions. The revised questionnaire of the BLS has therefore been able to capture crisis phenomena and address and evaluate the ways in which monetary policy makers responded.[29]

Figures 7.9-7.11 summarize the results: while the left panel of Figure 7.9 depicts that increasing deposits were reported as the main source of liquidity by banks, the right panel reveals that the ECB's expanded asset purchases had an increasingly adverse effect on banks' profitability. In particular, the persistently compressed net interest margins weigh negatively on profits, which cannot be compensated by the capital gains resulting from asset sales.

In addition, Figure 7.10 depicts that the banks in the euro area used the additional li-

[28]In June 2016, the Eurosystem launched its corporate sector purchase program (CSPP). Accordingly, the impact of the CSPP on banks' financial situation is firstly included in the BLS of 2016Q3.
[29]For a detailed description of the evolution of the BLS since the onset of the crisis, see Bundesbank (2016a).

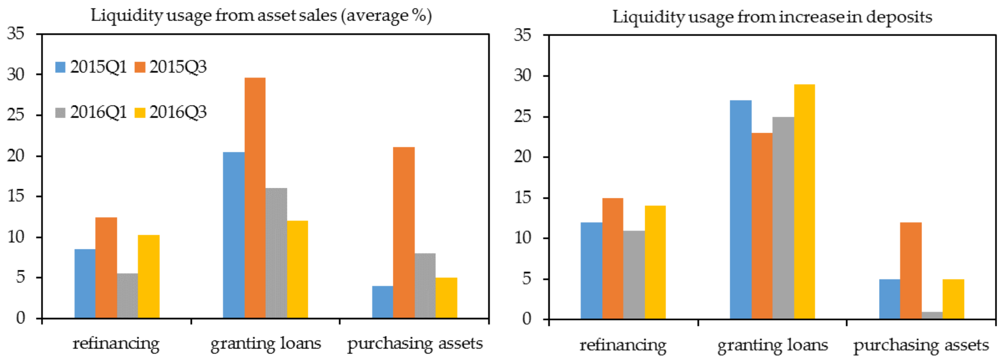

Figure 7.10.: Usage of liquidity from APP by euro area banks ⋄ *Note:* Average percentages are defined as the sum of the percentage for "has contributed considerably to this purpose" and "has contributed somewhat for this purpose" ⋄ *Source:* Data obtained from the respective bank lending surveys (ECB, 2015b,c, 2016a,b)

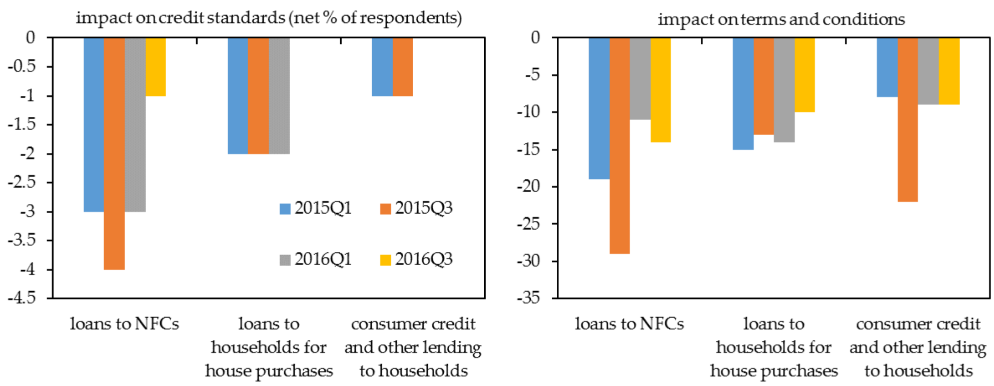

Figure 7.11.: Impact of APP on bank lending conditions ⋄ *Note:* Net percentages are defined as the difference between the sum of the percentages for "tightened considerably" and "tightened somewhat" and the sum of the percentages for "eased considerably" and "eased somewhat" ⋄ *Source:* Data obtained from the respective bank lending surveys (ECB, 2015b,c, 2016a,b)

quidity from the APP predominantly to grant loans, while asset purchases or the substitution of alternative refinancing was less important. Consequently, this suggests that the APP had a bigger impact through the bank lending than through the reserve-induced portfolio effect sketched out in section 5.1.3.

Finally, the negative values of Figure 7.11 indicate that the net percentage of banks report an easing of credit standards due to the APP, even though positive influence seems to vanish over time, especially for households. With respect to credit conditions, on the other hand, still a substantial amount of euro area banks reports a net easing impact of the APP. In line with the evidence displayed in Figure 7.10, the right panel of Figure 7.11 shows that the APP had the largest impact on the credit conditions for loans to non-financial corporations.

To sum up, the empirical evidence generally suggests that up to now the ECB's unconventional operations had a positive net effect on the supply of bank loans in the euro area. Specifically, as equity prices of banks holding a larger share of sovereign bonds benefited more from the increase in government bond prices following the ECB's purchases, it seems that one of the main impacts of the APP was to relieve banks' capital constraints through positive valuation effects on bank assets (Andrade et al., 2016a). Among other things, however, a protracted period of low lending rates will continue to drag on banks' profitability, which points to a decreasing marginal effect of additional unconventional measures. As the profitability issues tend to increase when older, higher yielding assets mature, policymakers in the future need to carefully balance the risks and benefits of persistently low interest rates.

7.3.3. Evidence for the US

A few related studies find supportive evidence for the bank lending channel in the US. Carpenter et al. (2015) analyze US flow of funds data related to the Fed's LSAP1 (from November 2008 to June 2010); LSAP2 (from November 2010 to June 2011); and the reinvestment program for proceeds of the Fed's maturing MBS holdings (from August 2010 to December 2012). Although the direct counterparties of the Fed's open-market operations are the primary dealers (a subset of banks), Carpenter et al. (2015) uncover that the ultimate counterparts of the Fed's treasury purchases were households (including hedge funds), and to a lesser extent broker-dealers and insurance companies. This is an important finding as it indicates that the Fed purchased ultimately from *non-banks*, which is a crucial condition for the bank lending channel of unconventional policies.

Interestingly, however, Figure 7.12 depicts that official asset purchases and US deposits net of interbank loans co-move only for LSAP2 and LSAP3, but diverge for LSAP1. This suggests that the conditions for the deposit-induced bank lending channel were

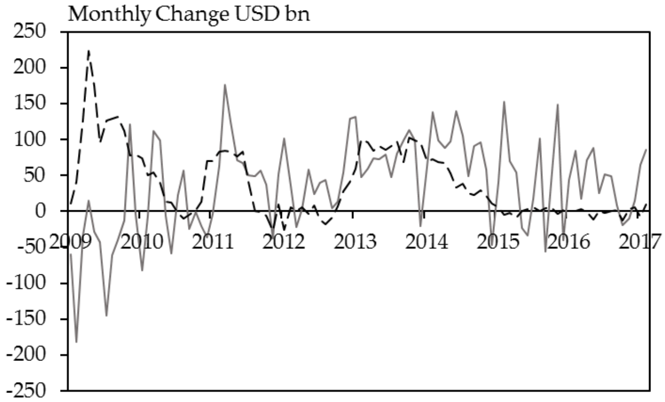

Figure 7.12.: Fed asset purchases and US commercial bank liabilities net of interbank loans ⋄ Fed asset purchases are calculated as monthly averages of Fed holdings of MBS, Treasury and agency bonds. Changes in bank liabilities are two-month moving averages. ⋄ *Source:* FED FRED, Datastream

met for LSAP2 and LSAP3, but not for LSAP1. As already discussed in section 7.2.4, LSAP1 took place in a period of severe market stress. Therefore, this program likely contributed to an orderly deleveraging of banks' balance sheets, instead of promoting *additional* bank lending.

The expansionary effect of LSAP2 and LSAP3 on bank lending activity is confirmed by Kandrac and Schlusche (2016). Using a bank-level dataset in combination with an instrument variable approach to account for the inherent endogeneity problem of bank lending and reserve creation, the authors find that banks which were experiencing an inflow of reserves increased their loan supply significantly.[30] Moreover, they show that higher reserves also induced increased risk-taking within banks' credit portfolios. In particular, their estimates imply that excess reserves caused annualized loan growth

[30] Kandrac and Schlusche (2016) use a regulatory change in the assessment of banks' contribution to the FDIC's Deposit Insurance Fund to instrument for reserves. In essence, the regulatory change made reserve holdings more expensive for banks covered by deposit insurance, but not for uninsured banks (since they are exempt from the FDIC fee). As the uninsured banks were exactly those who ended up holding the reserves, the authors instrument "reserve expansion" with a dummy variable indicating if a depository was exempt from the FDIC fee. Since a bank's exemption status is very likely to be uncorrelated with a bank's response to the monetary authority's reserve injection, the exogeneity of this instrument seems plausible.

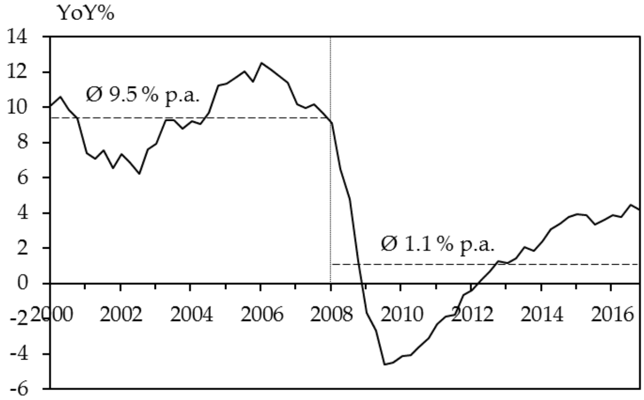

Figure 7.13.: US bank lending to the private sector ⋄ Adjusted for loan sales and securitization ⋄ *Source:* Fed Fred, Datastream

rates to be about 5.5 percentage points higher during LSAP2 and LSAP3, but had no significant impact during LSAP1 (Kandrac and Schlusche, 2016, p. 18). The evolution of US private sector loan growth displayed in Figure 7.13 broadly supports this result. Most of all, however, it should be noticed that the empirical study of Kandrac and Schlusche (2016) captures only the reserve-induced effect on bank's lending supply.[31] By construction, the study thus abstracts from any effects related to the type of assets being purchased. Based on economic theory, however, one hypothesis is that the type of asset the central bank purchases plays a critical role for the effectiveness of LSAPs.

In line with this hypothesis, Rodnyansky and Darmouni (2016) find that LSAP2 had no significant effect on bank lending, because it focused exclusively on Treasuries, which, however, are only perfect substitutes for the newly issued reserves.[32] This contrasts with LSAP1 and LSAP3, which, besides Treasuries, also included significant amounts of MBS purchases. In turn, banks with relatively large MBS holdings increased their loan supply more strongly in response to official asset purchases than those with relatively low holdings. More precisely, highly affected banks are found to have increased lending supply by about 2-3 percent relative to their non-affected counterparts.

Finally, two contemporary papers, Chakraborty et al. (2016) as well as Di Maggio et al.

[31] The reserve-induced effect of this section thus represents the logical counterpart to the reserve-induced portfolio balance effect of section 5.1.3, yet this time with respect to bank loans instead of government bonds.

[32] Since the empirical strategy of Rodnyansky and Darmouni (2016) focuses only on the asset side of bank's balance sheets, their estimates do not capture the effects that may arise from deposit inflows due to Treasury purchases from non-banks.

(2016), provide further supportive evidence for the bank lending channel of US unconventional policies. The former finds that banks more active in the MBS market increased their mortgage origination market share following LSAP1 and LSAP3, but showed no significant reaction to LSAP2.[33] The latter documents that the yields of eligible MBS experienced a significantly stronger decline than non-eligible MBS. Specifically, they show that average loan rates fell by about 100 basis points following LSAP1, while the rates of non-eligible MBS fell by only 40-50 basis points. In contrast, mortgage rates following LSAP2 and LSAP3 decreased by about 20-40 basis points, yet without any notable differences between conforming and non-conforming segments. That LSAP1 and LSAP3, which both involved MBS purchases, had such asymmetric effects suggests that the banking sector was much less healthy during LSAP1 than during LSAP3. Consistent with the theoretical foundations presented above, this highlights how LSAPs can offset the decline in bank lending, especially when private financial intermediation is facing binding capital constraints (see also Gertler and Karadi, 2011, 2013).

7.3.4. Concluding Remarks

Overall, the empirical evidence on the bank lending channel of unconventional monetary policies across three major central banks (the BoE, the Fed, and the ECB) suggests the following conclusions: firstly, non-standard liquidity enhancements prior to the failure of Lehman Brothers seem to have had a positive impact on bank lending, as central banks effectively took over the role of disrupted interbank markets. With the ongoing deterioration of bank capital and the persistent economic slump that followed the failure of Lehman Brothers, the positive impact of additional liquidity injections increasingly receded. Subsequently, any stimulating effect of monetary policy on bank lending acted mainly through the bank capital channel.

[33] In fact, credit easing in the MBS market was exactly what policymakers intended to achieve with the MBS purchases. The reduction in secondary MBS yields should be passed through to the primary loan rate, thereby stabilizing the US housing market (Bernanke, 2012a).

8. A DSGE Model of the Portfolio Balance Effect

While the renewed interest in the portfolio balance effect mainly emanates from the recent rounds of QE, its main functioning has been discussed in academia already half a century ago. In fact, the initial contributions to this effect go back to the seminal work of Modigliani and Sutch (1966), Tobin (1969), Brunner and Meltzer (1973), Friedman and Schwartz (1982), and was lately famously restated by Bernanke (2012b). However, neither of these authors examined the portfolio balance effect in a micro-founded DSGE framework. In this respect, the model by Andrés et al. (2004) is one of the first contributions in the DSGE literature incorporating the portfolio balance effect. Since the latter is arguably one of the most important transmission channels of QE, the following section starts with a thorough review of the model by Andrés et al. (2004) (ALSN-model).

The full-blown ALSN-model includes heterogeneous households and imperfect asset substitutability. However, to highlight the essential mechanisms at work, I first consider a baseline version with homogeneous households (section 8.1). In the baseline model, only unrestricted households exist for whom money and bonds serve as perfect substitutes. They are called *unrestricted* because they are free to invest in the entire asset horizon. Then, in section 8.2, the model is extended to include imperfect asset substitutability and heterogeneity among households. Technically, this is done by incorporating liquidity frictions in the long-term bond market. Finally, in section 8.3.2, the model is simulated subject to different shock experiments.

8.1. Baseline Model with Perfect Asset Substitutability

8.1.1. Households

In the baseline model a representative household demands C_t units of a Dixit-Stiglitz aggregate consumption good. The consumption bundle C_t consists of a continuum of differentiated goods j,

$$C_t = \left(\int_0^1 C_t(j)^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}}, \qquad \langle 8.1 \rangle$$

where ϵ denotes the household's elasticity of substitution between the differentiated consumption goods. Transactions in the goods market are processed with money and M_t/P_t denotes households' end-of-period real money balances. To earn money for consumption, each household supplies N_t hours of labor. Hence, the representative household seeks to maximize

$$\max_{C_t, N_t, M_t, B_t, B_{L,t}} E \sum_{t=0}^{\infty} \beta^t \left\{ a_t \left[U\left(\frac{C_t}{(C_{t-1})^h} \right) + V\left(\frac{M_t}{e_t P_t} \right) - \frac{(N_t)^{1+\varphi}}{1+\varphi} \right] - G(.) \right\} \qquad \langle 8.2 \rangle$$

where $\beta \in (0,\ 1)$ is the stochastic discount factor, a_t stands for an intertemporal preference shock, and $\varphi \geq 0$ is the inverse of the Frisch elasticity of labor supply. The sub-utility of consumption is given by

$$U(.) = \frac{1}{1-\sigma} \left(\frac{C_t}{(C_{t-1})^h} \right)^{1-\sigma} \qquad \langle 8.3 \rangle$$

with $\sigma > 0$ determining the household's relative risk aversion which equals the inverse of the intertemporal elasticity of substitution. Moreover, households display internal habit formation measured by the size of $h \in [0,\ 1]$. Incorporating habit persistence helps to explain the high serial correlation in the response of output to monetary policy shocks – a phenomenon that is incompatible with purely forward looking behavior and intertemporal separability of consumption (Fuhrer, 2000; Christiano et al., 2005).[1] The sub-utility function defining real money balances is given by

$$V(.) = \frac{1}{1-\delta} \left(\frac{M_t}{e_t P_t} \right)^{1-\delta} \qquad \langle 8.4 \rangle$$

where δ is related to the interest elasticity of money demand and e_t represents an AR(1) money demand shock. Finally, equation ⟨8.2⟩ includes portfolio adjustment costs, which

[1] Notice that if h equals zero, the standard result of time-separable utility would be obtained. On the other hand, if h equals unity, only the ratio of current to previous period's consumption would matter.

are specified as[2]

$$G(.) = \frac{d}{2}\left\{exp\left[c\left(\frac{M_t/P_t}{M_{t-1}/P_{t-1}} - 1\right)\right] + exp\left[-c\left(\frac{M_t/P_t}{M_{t-1}/P_{t-1}} - 1\right)\right] - 2\right\}. \qquad \langle 8.5\rangle$$

This kind of adjustment costs was first introduced by Nelson (2002) and for non-trivial results, d and c need to be strictly positive. Adjustment costs accrue each time households shift their portfolio allocation between money and bonds and serve as the rationale justifying the model's money-in-the-utility specification: Since money is needed in every goods market transaction, the representative household demands a certain amount of money as it tries to economize on the adjustment costs associated with planned consumption. That is, households demand real money balances even if there is a positive opportunity cost of holding money. In other words, adjustment costs serve as a means of modeling a liquidity premium on money.[3] This constitutes a difference to the the baseline NK model, where money carries no non-pecuniary return, so that in equilibrium either M_t equals zero (the cashless limit), or the nominal return on money must equal the riskless rate (Woodford, 2003, pp. 69)

8.1.2. Bond Market

Another important extension to the baseline NK model is the presence of bonds with different maturities. Besides money, unrestricted households can either invest in short- or long-term bonds (B_t and $B_{L,t}$). Both bonds are modeled as zero-coupon bonds that households buy at their nominal price B_t/i_t, respectively $B_{L,t}/(i_{L,t})^L$. Here, i_t and $i_{L,t}$ are nominal gross returns and it holds that $L > 1$ (in quarters), implying that $i_{L,t} > i_t \geq 0$. Following Svensson (2000), long-term bonds are modeled as zero-coupon bonds in order to simplify the analysis by excluding coupon payments to households during the bond holding period. Moreover, no secondary market for long-term bonds exists. This

[2]Equation ⟨8.5⟩ differs slightly (by the location of the brackets) from the adjustment costs used in Andrés et al. (2004, p. 669).

[3]An alternative assumption that generates a role for money is made by the so-called cash-in-advance constraint. CIA-models generally assume a certain timing structure between asset and goods markets. In the classical contribution of Lucas and Stokey (1987), agents are able to allocate their portfolios between cash bonds at the start of each period *at zero costs*, but they are forced to do so *prior* to their consumption decisions. Formally, this is modeled by including real money balances not directly in the utility function, but adding them to an otherwise standard budget constraint, thereby forming a cash-in-advance constraint (Walsh, 2010, cf. Ch. 3). Similar to the MIU-framework, this CIA-constraint generates a demand for money that is just sufficient to finance planned consumption, even if there is a positive opportunity cost of holding money. Therefore, substituting the MIU-approach of the initial ALSN-model with a CIA-constraint in the budget constraint would produce similar results.

entails that long-term bonds must be held until maturity, implying that neither capital gains nor losses are realized by trading in existing securities! This simplifies the analysis considerably. However, from an economic perspective, simply excluding a secondary market for long-term bonds seems like an arbitrary assumption. As discussed in section 4.2, however, the theoretical foundation could be based on the *preferred-habitat theory*.

A more technical vindication for excluding secondary markets is that allowing for long-term bonds to be traded and to yield coupon payments during the term to maturity would imply for a L-period bond that additional $2L$ terms would appear in the intertemporal budget constraint of both the household and the government (and thus also in the optimality condition of long-term bonds). Especially for longer maturities, this would imply a serious, potentially intractable complication. But since the key findings of the model do not rely on whether long-term bonds yield coupons or capital gains before maturity, I stick to this assumption mainly for mathematical convenience.

With this bond market structure, the household's intertemporal budget constraint is given by

$$\frac{M_t}{P_t} + \frac{B_t}{i_t P_t} + \frac{B_{L,t}}{(i_{L,t})^L P_t} + C_t \leq \frac{M_{t-1}}{P_t} + \frac{B_{t-1}}{P_t} + \frac{B_{L,t-L}}{P_t} + \frac{W_t N_t}{P_t} + \frac{T_t}{P_t} + \frac{D_t}{P_t}. \qquad \langle 8.6 \rangle$$

Households enter period t with money holdings M_{t-1} and maturing one-period bonds B_{t-1}. In addition, they receive income from labor ($W_t N_t$), transfers (T_t), dividends (D_t), and from maturing long-term bonds $B_{L,t-L}$ they purchased in period $t - L$. Together, these components constitute the income stream on the right-hand side of the budget constraint. Households use the proceeds for consumption C_t, and allocate their remaining wealth into money, short-term, and long-term bonds (left-hand side of the budget constraint). Hence, the household's constraint maximization problem yields the following optimality conditions:[4]

$$a_t \frac{(C_t)^{-\sigma}}{(C_{t-1})^{h-\sigma h}} - \beta h a_{t+1} \frac{(C_{t+1})^{1-\sigma}}{(C_t)^{1+h-\sigma h}} = \Lambda_t \qquad \langle 8.7 \rangle$$

$$\Lambda_t \left(\frac{W_t}{P_t} \right) = a_t (N_t)^{\varphi} \qquad \langle 8.8 \rangle$$

$$\Lambda_t \frac{1}{P_t r_t} = \beta \mathrm{E}_t \frac{\Lambda_{t+1}}{P_{t+1}} \qquad \langle 8.9 \rangle$$

[4]See Appendix B.6 for details on the optimization calculus.

$$\Lambda_t \frac{1}{P_t(i_{L,t})^L} = \beta^L \mathrm{E}_t \frac{\Lambda_{t+L}}{P_{t+L}} \tag{8.10}$$

$$a_t V_{t,M_t} - \{G_{t,M_t} + \beta \mathrm{E}_t \{G_{t+1,M_t}\}\} = \frac{\Lambda_t}{P_t} - \beta \mathrm{E}_t \frac{\Lambda_{t+1}}{P_{t+1}} \tag{8.11}$$

With habit persistence ($h > 0$) the optimality condition ⟨8.7⟩ links the marginal utility of wealth (the Lagrange multiplier of the budget constraint) to the sum of the marginal utility of current and future consumption. The *intra*temporal trade-off between consumption and hours worked is expressed by equation ⟨8.8⟩, stating that the optimal labour supply is determined by the the real wage times the marginal utility of wealth. Since working yields disutility, it has to be rewarded with a higher real wage to yield a marginal increase in consumption. Equations ⟨8.9⟩ and ⟨8.10⟩ are the Euler equations for short- and long-term bonds. Together with equation ⟨8.7⟩, they constitute the two *inter*temporal optimality conditions, implying that the marginal disutility of sacrificing consumption today has to equal the marginal increase in consumption tomorrow (in L-periods). Equation ⟨8.11⟩ is the Euler equation for real balances. It shows that the household's optimal demand for real balances is critically governed by marginal adjustment costs (G_{t,M_t}) and marginal real balances (V_{t,M_t}). As shown in the Appendix B.6, performing a log-linearization of equation ⟨8.7⟩ yields the aggregate Lagrange multiplier

$$\hat{\Lambda}_t = \frac{(\sigma-1)h}{1-\beta h}\hat{y}_{t-1} - \frac{\sigma + (\sigma-1)\beta h^2 - \beta h}{1-\beta h}\hat{y}_t + \frac{(\sigma-1)\beta h}{1-\beta h}\hat{y}_{t+1} + \frac{1-\beta h \rho_a}{1-\beta h}\hat{a}_t$$

$$\Leftrightarrow \hat{\Lambda}_t = \phi_1 \hat{y}_{t-1} - \phi_2 \hat{y}_t + \beta\phi_1 \hat{y}_{t+1} + \frac{1-\beta h\rho_a}{1-\beta h}\hat{a}_t, \tag{8.12}$$

where

$$\phi_1 = \frac{(\sigma-1)h}{1-\beta h}, \qquad \phi_2 = \frac{\sigma + (\sigma-1)\beta h^2 - \beta h}{1-\beta h}.$$

This gives a first indication how habit persistence influences the demand equation: Besides current output, previous as well as next period's output matters for the households intertemporal consumption decision.

Term Structure Log-linearizing equations ⟨8.9⟩ and ⟨8.10⟩ results in

$$\hat{\Lambda}_t = \hat{r}_t + \mathrm{E}_t\hat{\Lambda}_{t+1}, \tag{8.13}$$

$$\hat{\Lambda}_t = L\hat{r}_{L,t} + \mathrm{E}_t\hat{\Lambda}_{t+L}, \tag{8.14}$$

where the Fisher equations

$$\hat{r}_t = \hat{i}_t - \mathrm{E}_t \hat{\pi}_{t+1} \tag{8.15}$$

$$\hat{r}_{L,t} = \hat{i}_{L,t} - \frac{1}{L}\mathrm{E}_t \sum_{j=0}^{L-1} \hat{\pi}_{t+j+1} \tag{8.16}$$

were used to substitute the nominal with the real interest rates ($\hat{r}_t$, respectively $\hat{r}_{L,t}$). Hence, equations ⟨8.13⟩ and ⟨8.14⟩ can be combined to approximate the common expectations theory of the term structure, which is given by

$$\hat{r}_{L,t} = \frac{1}{L}\sum_{j=0}^{L-1} \hat{r}_{t+j}. \tag{8.17}$$

The fact that short- and long-term bonds are perfect substitutes in this baseline version of the model gives rise to the standard arbitrage mechanism which ensures that the long-term rate is equal to the average sequence of short-term rates. Finally, combining the first order conditions for short-term bonds and money yields the household's money demand function

$$a_t V_{t,M_t} - \{G_{t,M_t} + \beta \mathrm{E}_t \{G_{t+1,M_t}\}\} = \frac{\Lambda_t}{P_t} - \frac{\Lambda_t}{i_t P_t} = \frac{\Lambda_t}{P_t}\left(1 - \frac{1}{i_t}\right) = \frac{\Lambda_t}{P_t}\left(\frac{i_t - 1}{i_t}\right) \tag{8.18}$$

which can be log-linearized to

$$\hat{m}_t = \mu_1 \hat{m}_{t-1} + \mu_2 \hat{m}_{t+1} - \mu_3(\hat{\Lambda}_t - \hat{a}_t) - \mu_4 \hat{i}_t + \mu_5 \hat{e}_t. \tag{8.19}$$

The coefficients in equation ⟨8.19⟩ are convolutions of parameters, i.e.

$$\delta_0 = dc^2\delta^{-1}m^{\delta-1}, \quad \mu_1 = \frac{\delta_0}{1+\delta_0(1+\beta)}, \quad \mu_2 = \beta\mu_1,$$

$$\mu_3 = \frac{1}{\delta(1+\delta_0(1+\beta))}, \quad \mu_4 = \frac{1}{\delta(i-1)(1+\delta_0(1+\beta))}, \quad \mu_5 = \frac{\delta-1}{\delta(1+\delta_0(1+\beta))}.$$

As usual in this class of models, money demand is negatively related to the nominal interest rate $\hat{i}_t$, whereas shocks to preferences $\hat{a}_t$ and money demand shocks $\hat{e}_t$ are exogenous and enter the equation with a positive sign. The fact that lagged and future real balances are part of equation ⟨8.19⟩ is due to the marginal adjustment costs that appear in equation ⟨8.18⟩. To better grasp the idea of how adjustment costs modify households' money demand, notice how equation ⟨8.19⟩ would look without them. Without any adjustment costs, i.e. with $d = 0$ and thus $G(.) = 0$, the parameter δ_0 would equal zero, too. As can be seen from the convolutions of parameters, this would entail that $\mu_1 = \mu_2 = 0$, such that lagged and future real money balances would drop out of equation ⟨8.19⟩.

If households face positive adjustment costs, however, they compare the nominal interest rate – the opportunity cost of real money balances – with the adjustment costs that accrue when they shift their portfolio between money and bonds. Thus, if households expect their real income to be higher next period, they know they will need higher real balances to transact in the goods market next period. As a consequence, households will increase their money demand already today, if they are not discouraged by a sufficient rise in the nominal interest rate $\hat{i}_t$. Notice that in this baseline version of the ALSN-model, adjustment costs are the theoretical foundation that give rise to real balances in the utility function. Besides habit persistence, they represent the only extension to an otherwise standard NK model, as laid out in section 3.1.

8.2. Implications of Imperfect Asset Substitution

In this section, in order to demonstrate the portfolio balance channel of central bank open market operations, two additional frictions are added to the baseline model. First, it is assumed that transaction costs in the long-term bond market are subject to stochastic shock process ς_t with zero mean and finite variance. The main purpose of including this shock is to account for time-varying exogenous movements in the term premium that result either in an aggregate benefit or loss for the household sector. Second, and more significantly, the assumption of perfect asset substitution will be abrogated. If households do not have preferred habits for longer-term securities in general, purchasing long-term bonds implies a loss of liquidity compared to investments in short-term bonds, since long-term bonds must be held until their maturity date. As a consequence, investments in long-term bonds carry a higher risk than nominally equivalent investments in short-term bonds, forcing households to hedge this (liquidity) risk by holding some kind of self-imposed "reserve requirements" whenever they enter the long-term bond market. Economically, the absence of a secondary market for long-term bonds has the same effect as a more sophisticated strategy of modelling long-term bonds subject to time-varying interest rate risk. Compared to the latter, it represents a convenient way to account for an endogenous term premium in a still tractable DSGE model of the portfolio balance effect.

8.2.1. Households

Technically, imperfect asset substitution stems from a liquidity friction that takes the form of an additional cost function in the household's optimization problem. This cost function depends on the relative holdings of imperfect substitutes, M_t and $B_{L,t}$, and is specified as

$$H(.) = \frac{\upsilon}{2}\left[\frac{M_t}{B_{L,t}}\eta - 1\right]^2, \qquad \langle 8.20\rangle$$

where υ measures the relative strength of a household's liquidity preference. The higher the value of υ, the higher are the illiquidity costs associated with an investment in long-term bonds. The parameter η depicts the inverse of the steady state level of the money to long-term bond ratio. Specifying the cost function $H(.)$ in this way ensures that its steady state value is equal to zero. With this additional cost function, the household's optimization problem changes to

$$\max E\sum_{t=0}^{\infty}\beta^t\left\{a_t\left[U\left(\frac{C_t}{(C_{t-1})^h}\right)+V\left(\frac{M_t}{e_t P_t}\right)-\frac{(N_t)^{1+\varphi}}{1+\varphi}\right]-G(.)-H(.)\right\} \qquad \langle 8.21\rangle$$

and the intertemporal budget constraint is given by

$$\frac{M_t}{P_t}+\frac{B_t}{P_t i_t}+\frac{(1+\varsigma_t)B_{L,t}}{P_t(i_{L,t})^L}+C_t \leq \frac{M_{t-1}}{P_t}+\frac{B_{t-1}}{P_t}+\frac{B_{L,t-L}}{P_t}+\frac{W_t N_t}{P_t}+\frac{T_t}{P_t}+\frac{D_t}{P_t}. \qquad \langle 8.22\rangle$$

As only the endogenous variables M_t and $B_{L,t}$ appear in equation ⟨8.20⟩, only these optimality conditions change relative to the baseline model. They are given by

$$\frac{\partial\mathcal{L}}{\partial M_t} = a_t V_{t,M_t} - \{G_{t,M_t}+\beta \mathrm{E}_t G_{t+1,M_t}\} - \frac{\upsilon\eta}{B_{L,t}}\left[\frac{M_t}{B_{L,t}}\eta - 1\right] = \frac{\Lambda_t}{P_t}\left(\frac{i_t-1}{i_t}\right), \qquad \langle 8.23\rangle$$

$$\frac{\partial\mathcal{L}}{\partial B_{L,t}} = -\frac{\upsilon\eta M_t}{B_{L,t}^2}\left[\frac{M_t}{B_{L,t}}\eta - 1\right] + \frac{1+\varsigma_t}{(i_{L,t})^L}\frac{\Lambda_t}{P_t} = \beta^L \mathrm{E}_t\frac{\Lambda_{t+L}}{P_{t+L}}. \qquad \langle 8.24\rangle$$

The innovation with imperfect asset substitutability is now that an increase in the supply of long-term bonds relative to money reduces the value of the cost term that reflects the imperfect substitutability between both assets. Notice that absent any friction

$$\varsigma_t = \frac{\upsilon\eta M_t}{B_{L,t}^2}\left[\frac{M_t}{B_{L,t}}\eta - 1\right] = 0, \tag{8.25}$$

such that both conditions would collapse into their baseline representation. With active liquidity frictions, however, real money demand is modified to

$$\hat{m}_t = \mu_1\hat{m}_{t-1} + \mu_2\hat{m}_{t+1} - \mu_3(\hat{\Lambda}_t - \hat{a}_t) - \mu_4\hat{i}_t + \mu_5\hat{e}_t - \frac{\upsilon m^{\delta-1}}{\delta(1+\delta_0(1+\beta))}(\hat{m}_t - \hat{b}_{L,t}). \tag{8.26}$$

Except for the last term on the right hand side, equation ⟨8.26⟩ resembles its baseline counterpart of equation ⟨8.19⟩. This illustrates that with imperfect substitutability a relative increase in the supply of the more *illiquid* asset increases the money demand, and vice versa. Those insights provide some important preliminary results: since the optimality conditions for money and long-term bonds are a function of steady state deviations from an optimal asset relation, monetary policy can exploit this fact by manipulating the relative supply of money to long-term bonds using unconventional open-market operations.

In a next step, this information will be used to derive the term structure of interest rates under imperfect asset substitution. In principle, the term structure is obtained – as in the benchmark case – by combining the optimality conditions for short- and long-term bonds. Since the first has not changed with respect to the benchmark case, equation ⟨8.13⟩ still holds, which was given by

$$\hat{\Lambda}_t = \hat{r}_t + \mathrm{E}_t\hat{\Lambda}_{t+1}. \tag{8.13}$$

The second condition, however – the first order condition for long-term bonds – has changed due to the liquidity friction. The log-linearized version of equation ⟨8.24⟩ equals[5]

$$\hat{\Lambda}_t = L\hat{r}_{L,t} + \mathrm{E}_t\hat{\Lambda}_{t+L} - \varsigma_t + \tau(\hat{m}_t - \hat{b}_{L,t}) \tag{8.27}$$

with

$$\tau = \frac{\upsilon(i_L)^L(i-1)}{ib_L m^{-\delta}} \tag{8.28}$$

[5] Again, for a detailed derivation of the linearization process, the reader may refer to Appendix B.6

and b_L as the the steady state value of real long-term bonds holdings.[6] Setting equation ⟨8.13⟩ equal to ⟨8.27⟩ and solving for the long-term real rate, yields

$$\hat{r}_{L,t} = \frac{1}{L}\sum_{j=0}^{L-1} \hat{r}_{t+j} + \frac{1}{L}\left(\varsigma_t - \tau(\hat{m}_t - \hat{b}_{L,t})\right). \quad \langle 8.29 \rangle$$

This expression for the term structure deviates from its pure expectational form by a term premium

$$tp_t = L\hat{r}_{L,t} - \sum_{j=0}^{L-1} \hat{r}_{t+j} = (\varsigma_t - \Phi_t)\,, \quad \langle 8.30 \rangle$$

which consists of the exogenous transaction cost shock ς_t and an endogenous component, $\Phi_t = \tau(\hat{m}_t - \hat{b}_{L,t})$, representing log-deviations of money and long-term bond holdings from steady state. The source of the endogenous component is the missing secondary market for long-term bonds and – as shown by equation ⟨8.28⟩ – the relative strength of this friction is critically determined by the household's liquidity preference v: The higher the liquidity preference, the higher will be the self-imposed liquidity buffer that households choose to hold when they enter the long-term bond market. Finally, the information from equation ⟨8.29⟩ can be used to substitute out $\hat{m}_t$ and $\hat{b}_{L,t}$ in the money demand equation ⟨8.26⟩. Thereby, the latter can be transformed to

$$\begin{aligned}\hat{m}_t = {} & \mu_1 \hat{m}_{t-1} + \mu_2 \hat{m}_{t+1} - \mu_3(\hat{\Lambda}_t - \hat{a}_t) \\ & - \mu_4 \hat{i}_t + \mu_5 \hat{e}_t + \mu_6 \left(L\hat{r}_{L,t} - \sum_{j=0}^{L-1} \hat{r}_{t+j} - \varsigma_t \right) \quad \langle 8.31 \rangle\end{aligned}$$

with

$$\mu_6 = \frac{i}{i-1}\frac{\eta}{(i_L)^L \delta(1+\delta_0(1+\beta))}.$$

This represents a more generalized version of the standard money demand relations that incorporate imperfect asset substitutability and portfolio adjustment costs.[7] As outlined above, adjustment costs are the reason why leads and lags of real balances appear in the money demand equation. The elimination of the relative asset quantities, however, reveals that imperfect substitutability also implies that money demand is a function of the present discounted value of short- and long-term interest rates. Only the exoge-

[6] A more thorough discussion of the meaning of the parameter τ is given below.

[7] The coefficients μ_5 and μ_6 vary slightly from the ones in Andrés et al. (2004). But this difference has no material impact on the model dynamics.

nous component ς_t of the term premium remains in the money demand equation, whereas the endogenous part can be expressed in the form of interest rates.

8.2.2. Firms

The firms' optimization problem follows the standard approach of the basic New Keynesian Model as laid out in section 3.1.2. Hence, the optimal price is set according to equation ⟨3.21⟩, which is reprinted here for convenience:

$$P_t^* = \frac{\epsilon}{\epsilon - 1} \frac{\mathrm{E}_t \sum\limits_{k=0}^{\infty} \theta^k \beta^k C_{t+k}^{1-\sigma} P_{t+k}^{\epsilon} MC_{t+k|t}^{r}}{\mathrm{E}_t \sum\limits_{k=0}^{\infty} \theta^k \beta^k C_{t+k}^{1-\sigma} P_{t+k}^{\epsilon-1}} \qquad \langle 8.32 \rangle$$

8.2.3. Government

As usual in this class of models, the government sector is a consolidated entity comprising the central bank and the Treasury. Government liabilities consist of non-interest bearing money as well as interest-bearing short- and long-term debt. The government uses the proceeds from debt issuance and seignorage revenues to finance real transfers to households. Since the model's main focus lies on the monetary policy issues it abstracts – in line with the parsimony principle – from government consumption and other forms of fiscal policy. Hence, the consolidated government's budget constraint is given by

$$\frac{M_t}{P_t} + \frac{B_t}{i_t P_t} + \frac{B_{L,t}}{(i_{L,t})^L P_t} - \left(\frac{M_{t-1}}{P_t} + \frac{B_{t-1}}{P_t} + \frac{B_{L,t-L}}{P_t} \right) = \frac{T_t}{P_t}. \qquad \langle 8.33 \rangle$$

Furthermore, risky long-term bonds are assumed to follow a simple AR(1)-process of the form

$$\frac{B_{L,t}}{P_t} = \left(\frac{B_{L,t-1}}{P_{t-1}} \right)^{\rho_{b_L}} \exp(\epsilon_{B_{L,t}}) \qquad \langle 8.34 \rangle$$

where $\rho_{b_L} \in [0,1]$ and $\epsilon_{B_{L,t}}$ is an i.i.d. exogenous error process. With this kind of uncertainty about the value of a given long-term bond in period t, the government adjusts its short-term debt position such that its intertemporal budget constraint holds. In this manner, real transfers are set according to

$$\frac{T_t}{P_t} = -\varkappa \frac{B_{t-1}}{P_{t-1}} + \epsilon_t. \qquad \langle 8.35 \rangle$$

This fiscal rule ensures that real transfers in period t react inversely to previous period's short-term debt level and positively to an i.i.d. exogenous disturbance ϵ_t.

8.2.4. Monetary Policy

The central bank's policy instrument is the short-term nominal interest rate i_t. Based on Ireland (2004), conventional interest rate policy follows an augmented Taylor rule of the form

$$\hat{i}_t = \phi_i \hat{i}_{t-1} + (1-\phi_i)\left(\phi_\pi \hat{\pi}_t + \phi_y \hat{y}_t + \phi_\mu \hat{\mu}_t\right) + \epsilon_{i_t}, \qquad \langle 8.36\rangle$$

with

$$\hat{\mu}_t = \hat{m}_t - \hat{m}_{t-1} + \hat{\pi}_t. \qquad \langle 8.37\rangle$$

where ϕ_i is the interest-rate-smoothing parameter and ϕ_π and ϕ_y are the weights attached to inflation respectively output stabilization. Moreover, monetary policy also reacts to steady state deviations of real balances – and the strength of that reaction is governed by ϕ_μ.[8] The presence of real balances in in the central bank's reaction function can be based on money growth variability in the central bank's loss function, as suggested by Rudebusch and Svensson (2002). An alternative and, in the context of this model more suitable, rationalization could be the usefulness of monetary aggregates as indicators of inflation.[9]

8.2.5. Equilibrium Analysis

Market clearing conditions in the labor market requires

$$N_t = \int_0^1 N_t(j)dj. \qquad \langle 8.38\rangle$$

Simultaneously, for the goods market to clear, it must hold that

$$Y_t = C_t. \qquad \langle 8.39\rangle$$

[8] All parameters, ϕ_i, ϕ_π, ϕ_y, and ϕ_μ are are assumed to be non-negative and the perturbation ϵ_{i_t} is assumed to be normally distributed with a standard deviation of σ_{i_t}.

[9] However, the study of Rudebusch and Svensson (2002) indicates that the empirical justification for monetary policy reacting to money growth is rather weak. Even with constant money demand, the inclusion of monetary aggregates in the reaction function increases the variability of output and inflation compared to the first-best case of flexible inflation targeting (with a zero weight attached to money).

The supply side of the model is derived from log-linearizing equation ⟨8.32⟩. As shown in detail in appendix B.2 this entails that inflation evolves according to

$$\hat{\pi}_t = \beta \mathrm{E}_t \{\hat{\pi}_{t+1}\} + \bar{\lambda} \widehat{mc}_t^r \tag{8.40}$$

with $\bar{\lambda} = \frac{(1-\theta)(1-\theta\beta)}{\theta}\Theta = \frac{(1-\theta)(1-\theta\beta)}{\theta}\frac{1-\alpha}{1-\alpha+\alpha\epsilon}$. As in the baseline New Keynesian Phillips Curve, current inflation is driven by future inflation and real marginal costs. As a result of habit persistence, however, real marginal costs not only depend on current output and technology shocks ($\hat{z}_t$), but also on lagged and future output, as well as on preference shocks ($\hat{a}_t$). Hence, the functional form of real marginal costs differs from the baseline NK model and is given by

$$\widehat{mc}_t^r = (\chi + \phi_2)\hat{y}_t - \phi_1 \hat{y}_{t-1} - \beta\phi_1 \mathrm{E}_t \{\hat{y}_{t+1}\} - \frac{\beta h(1-\rho_a)}{1-\beta h}\hat{a}_t - (1+\chi)\hat{z}_t, \tag{8.41}$$

with

$$\chi = \frac{\varphi + \alpha}{1-\alpha}. \tag{8.42}$$

Since the returns to labor are marginally decreasing, the elasticity of labor with respect to output (α) and the elasticity of the labor supply (φ) matter for the relation between output and inflation through the parameter χ. Finally, the model is closed by assuming that preference shocks, money demand shocks, technology shocks, and transaction cost shocks follow univariate AR(1) processes:

$$\hat{a}_t = \rho_a \hat{a}_{t-1} + \epsilon_{a_t}, \tag{8.43}$$

$$\hat{e}_t = \rho_e \hat{e}_{t-1} + \epsilon_{e_t}, \tag{8.44}$$

$$\hat{z}_t = \rho_z \hat{z}_{t-1} + \epsilon_{z_t}, \tag{8.45}$$

$$\hat{\varsigma}_t = \rho_\varsigma \hat{\varsigma}_{t-1} + \epsilon_{\varsigma t} \tag{8.46}$$

where the ϵ denotes white noise shocks with zero mean and finite variance. So far, liquidity frictions in the long-term bond market cause an endogenous spread between the short- and long-term interest rate. In itself, however, this spread is *not* sufficient to affect aggregate demand. The reason is that any unrestricted household could just bypass the risky long-term bond market and enforce its consumption plan by trading in a sequence of short-term bonds. As a consequence – despite the endogenous term premium – only the expected path of short-term rates would matter for aggregate demand, leading to the standard result of the New Keynesian benchmark case. Only if asset markets are at least partially segmented can there be a role for the long-term rate that goes beyond the pure expectations theory of the term structure. This will be the topic of the next section.

8.3. Implications of Heterogeneous Households

Asset market segmentation is achieved by splitting the household sector into two groups: The first group are the so-called *unrestricted* households similar to the ones discussed in the preceding section. These households are *unrestricted* in the sense that they can freely allocate their funds within the entire asset horizon: money and long-term bonds as well as short-term bonds. The size of this group is given by the parameter λ.

The second group are the *restricted* households. They put their funds either in money or long-term bonds, but will never hold short-term bonds. Thus, restricted households can be conceived as preferred-habitat investors with particular preferences for longer maturities. Since investing in long-term bonds does not mean a liquidity loss to them, they refuse to hold "voluntary reserve requirements" when they enter the long-term bond market.

Hence, imperfect asset substitutability is applicable to *unrestricted* households only. Apart from that, both households are similar. The practical consequence of this modification is that the long-term rate appears in the dynamic IS-equation in a manner different from the pure sequence of future short-term rates. In combination with imperfect asset substitutability, this modification opens a new transmission channel for monetary policy. The central bank can now execute two effects on aggregate demand. Firstly, it can influence the path of current and future short-term real interest rates. And secondly, it can affect aggregate demand directly through its influence on the endogenous component of term premium.

Since the *unrestricted* households' decision problem is equivalent to the analysis performed in the previous section, the optimality conditions for short- and long-term bond holdings are simply given by

$$\hat{\Lambda}_t^u = \hat{r}_t + \mathrm{E}_t \hat{\Lambda}_{t+1}^u \qquad \langle 8.47 \rangle$$

$$\hat{\Lambda}_t^u = L\hat{r}_{L,t} + \mathrm{E}_t \hat{\Lambda}_{t+L}^u - \varsigma_t + \Phi_t \qquad \langle 8.48 \rangle$$

where ⟨8.30⟩ was used in ⟨8.27⟩ to account for the degree of imperfect asset substitution between money and bonds.

The situation is different for *restricted* households. Since they are unaffected by the liquidity frictions in the long-term bonds market, their respective optimality condition is just given by

$$\hat{\Lambda}^r_t = L\hat{r}_{L,t} + \mathrm{E}_t\hat{\Lambda}^r_{t+L}. \quad \langle 8.49\rangle$$

Accordingly, the *aggregate* Lagrange-multiplier for both types of households is given by the sum

$$\hat{\Lambda}_t = \lambda\hat{\Lambda}^u_t + (1-\lambda)\hat{\Lambda}^r_t, \quad \langle 8.50\rangle$$

where the weights λ and $(1-\lambda)$ correspond to the respective group size. This definition together with equations ⟨8.48⟩ and ⟨8.49⟩ results in

$$\hat{\Lambda}_t = \lambda\left(L\hat{r}_{L,t} + \mathrm{E}_t\hat{\Lambda}^u_{t+L} + \Phi^u_t - \varsigma_t\right) + L\hat{r}_{L,t} + \mathrm{E}_t\hat{\Lambda}^r_{t+L} - \lambda\left(L\hat{r}_{L,t} + \mathrm{E}_t\hat{\Lambda}^r_{t+L}\right)$$
$$\Leftrightarrow \hat{\Lambda}_t = \lambda(\Phi^u_t - \varsigma_t) + L\hat{r}_{L,t} + \mathrm{E}_t\hat{\Lambda}_{t+L}, \quad \langle 8.51\rangle$$

where equation ⟨8.50⟩ was iterated forward L-periods to substitute out $\hat{\Lambda}^u_{t+L}$ and $\hat{\Lambda}^r_{t+L}$, respectively. Combining the above expression with equation ⟨8.30⟩, yields

$$\hat{\Lambda}_t = \lambda\sum_{j=0}^{L-1}\hat{r}_{t+j} + (1-\lambda)L\hat{r}_{L,t} + \mathrm{E}_t\hat{\Lambda}_{t+L}. \quad \langle 8.52\rangle$$

I use this expression for the aggregate Lagrange-multiplier to derive the aggregate dynamic IS-equation. Therefore, equation ⟨8.52⟩ is plugged into the consumption Euler equation ⟨8.12⟩, which gives

$$\phi_1\hat{y}_{t-1} - \phi_2\hat{y}_t + \beta\phi_1\hat{y}_{t+1} + \frac{1-\beta h\rho_a}{1-\beta h}\hat{a}_t = \lambda\sum_{j=0}^{L-1}\hat{r}_{t+j} + (1-\lambda)L\hat{r}_{L,t} + \mathrm{E}_t\hat{\Lambda}_{t+L}. \quad \langle 8.53\rangle$$

This can be further simplified, by substituting $\mathrm{E}_t\hat{\Lambda}_{t+L}$ with equation ⟨8.52⟩ iterated L-periods ahead, to

$$\phi_1\hat{y}_{t-1} - \phi_2\hat{y}_t + \beta\phi_1\mathrm{E}_t\hat{y}_{t+1} + \frac{1-\beta h\rho_a}{1-\beta h}\hat{a}_t = \lambda\sum_{j=0}^{L-1}\hat{r}_{t+j} + (1-\lambda)L\hat{r}_{L,t}$$
$$+ \phi_1\hat{y}_{t+L-1} - \phi_2\hat{y}_{t+L} + \beta\phi_1\mathrm{E}_t\hat{y}_{t+L+1} + \left(\frac{1-\beta h\rho_a}{1-\beta h}\right)\rho_a^L\hat{a}_t. \quad \langle 8.54\rangle$$

Finally, solving equation ⟨8.54⟩ for y_t, and defining F as the forward operator, results in the dynamic IS-equation:

$$\phi_2(1-F^L)\hat{y}_t = \phi_1(1-F^L)\hat{y}_{t-1} + \beta\phi_1(1-F^L)\mathrm{E}_t\hat{y}_{t+1} - \lambda\sum_{j=0}^{L-1}\hat{r}_{t+j} - (1-\lambda)L\hat{r}_{L,t} + \left(\frac{1-\beta h\rho_a}{1-\beta h}\right)(1-\rho_a^L)\hat{a}_t. \quad \langle 8.55\rangle$$

As in the standard IS-equation with internal habit persistence, current output is a function of previous as well as future output. Furthermore, current output depends negatively on the sequence of real short-term rates and positively on the exogenous demand shock $\hat{a}_t$. In a frictionless world with homogeneous agents, equation ⟨8.55⟩ could be transformed into a second-order difference equation involving output and the real interest rate only. With imperfect asset substitutability and household heterogeneity, however, this is different. In such an environment, the dynamic IS-equation incorporates two distinct interest rates as well as future output in L-periods from now. The reason for this more general specification of the IS-equation is based on the liquidity frictions that give rise to the endogenous term premium as well as on the assumed asset market segmentation due to preferred-habitat investors.

Lastly, the aggregate money demand equation needs to be derived. From equations ⟨8.13⟩ and ⟨8.15⟩, it must hold that

$$\hat{i}_t = \hat{\Lambda}_t + \hat{\pi}_{t+1} - \hat{\Lambda}_{t+1}. \quad \langle 8.56\rangle$$

Moreover, since $i = \beta^{-1}$, one can show that

$$\mu_4 = \frac{\beta}{1-\beta}\mu_3. \quad \langle 8.57\rangle$$

Equations ⟨8.56⟩ and ⟨8.57⟩ can be used to rewrite the *unrestricted* households' money demand equation as

$$\hat{m}_t^u = \mu_1\hat{m}_{t-1}^u + \mu_2\mathrm{E}_t\hat{m}_{t+1}^u + \frac{\mu_3}{1-\beta}\hat{\Lambda}_t^u - \mu_3\hat{a}_t - \frac{\beta\mu_3}{1-\beta}\mathrm{E}_t\hat{\Lambda}_{t+1}^u + \frac{\beta\mu_3}{1-\beta}\hat{\pi}_{t+1} + \mu_5\hat{e}_t + \mu_6\left(L\hat{r}_{L,t} - \sum_{j=0}^{L-1}\hat{r}_{t+j} - \varsigma_t\right). \quad \langle 8.58\rangle$$

Except for the last term in equation ⟨8.58⟩ (which reflects the liquidity friction), *restricted* households face the same money demand function. It equals

$$\hat{m}^r_t = \mu_1 \hat{m}^r_{t-1} + \mu_2 \mathrm{E}_t \hat{m}^r_{t+1} + \frac{\mu_3}{1-\beta}\hat{\Lambda}^r_t - \mu_3 \hat{a}_t - \frac{\beta\mu_3}{1-\beta}\mathrm{E}_t\hat{\Lambda}^r_{t+1} + \frac{\beta\mu_3}{1-\beta}\hat{\pi}_{t+1} + \mu_5 \hat{e}_t. \quad \langle 8.59\rangle$$

Aggregate money demand is thus calculated as

$$\hat{m}_t = \lambda \hat{m}^u_t + (1-\lambda)\hat{m}^r_t, \quad \langle 8.60\rangle$$

which is equal to

$$\hat{m}_t = \mu_1 \hat{m}_{t-1} + \mu_2 \mathrm{E}_t \hat{m}_{t+1} + \frac{\mu_3}{1-\beta}\hat{\Lambda}_t - \mu_3 \hat{a}_t - \frac{\beta\mu_3}{1-\beta}\mathrm{E}_t\hat{\Lambda}_{t+1} + \frac{\beta\mu_3}{1-\beta}\mathrm{E}_t\hat{\pi}_{t+1} + \mu_5 \hat{e}_t + \lambda\mu_6 \left(L\hat{r}_{L,t} - \sum_{j=0}^{L-1} \hat{r}_{t+j} - \varsigma_t \right). \quad \langle 8.61\rangle$$

Without any liquidity friction or market segmentation, this money demand would collapse into a static money demand equation including only current output and the current short-term nominal interest rate. Equation ⟨8.61⟩ deviates from this baseline on two grounds: firstly, portfolio adjustment costs imply that lagged and future output determines current real balances; secondly, imperfect asset substitution causes long-term rates distinct from the sequence of short-term rates to appear in the money demand equation.

8.3.1. Monetary Policy Implications

Given risk-averse investors, the key message from section 8.2 was that the portfolio balance effect crucially depends on the existence of an endogenous term which presupposes the denial of the expectations theory of the term structure. As emphasized by Cox et al. (1981) and Campbell et al. (1997), one should distinguish between the *Pure Expectations Hypothesis (PEH)* and the *Expectations Hypothesis (EH)*.[10] The PEH states that no expected excess returns (or term premia) exist, whereas the EH says that they might exist, but are non-zero and constant over time. Hence, the PEH is consistent only if interest rates are non-stochastic and investors are risk-neutral. On the other hand, if investors

[10] The latter is sometimes also referred to as the *Weak Expectations Hypothesis* in the literature.

are risk-averse, the no-arbitrage condition embedded in the EH requires that long-term bonds carry a constant term premium over short-term bonds.[11]

Importantly, however, even if a constant term premium existed in the baseline ALSN model (section 8.1), monetary policy had no direct control over it, since the term premium originates from policy-invariant deep parameters, i.e. household's risk-aversion. This implies that in both cases, with or without a risk correction for long-term bonds, monetary policy cannot control the long-term rate independently of the short-term rate! This basically summarizes the policy implications of the expectations theory of the term structure – may it be based on the PEH or on the EH: by setting the path of future overnight rates, the central bank can only indirectly determine the longer-term rate. Thus, both the baseline ALSN and the baseline New Keynesian model are *not* immune to Tobin's critique of the traditional IS-LM model, where "all nonmonetary assets and debts are... taken to be perfect substitutes at a common interest rate plus or minus exogenous interest rate differentials" (Tobin, 1982, p. 179).

The model of Andrés et al. (2004) departs from this hypothetical benchmark on essentially two modifications (which may, arguably, reflect a more realistic representation of the world): asset market segmentation due to heterogeneous agents and imperfect asset substitutability. Both modifications together predict an endogenous wedge between the long-term rate and the path of future short-term rates that monetary policy can target independently of the evolution of short-term rates. They offer an additional channel for monetary policy, where the long-term rate can be controlled independently of the short rate. The mechanism through which this channel operates is the central bank's impact on relative asset quantities in private portfolios.

To see how this DSGE-representation of the portfolio balance channel hinges on the key assumptions of imperfect substitutability and heterogeneous agents, I consider the following model variation: I assume that the asset market friction matters for both types of households, not solely for the *unrestricted*, as above. Now, *restricted* and *unrestricted* households value long-term bonds as imperfect substitutes for money. Technically, this involves that both households' first-order conditions for long-term bond holdings look identical and include the endogenous part of the term premium, $\Phi_t = \tau(\hat{m}_t - \hat{b}_{L,t})$. The result for the aggregate Lagrange-multiplier is thus given by

$$\hat{\Lambda}_t = L\hat{r}_{L,t} + \mathrm{E}_t\hat{\Lambda}_{t+L} - \varsigma_t + \Phi_t \qquad \langle 8.62 \rangle$$

[11] Cf. Geiger (2011) for a thorough discussion on risk premia and their different implications for the yield curve.

which, using equation ⟨8.29⟩, can be simplified to

$$\hat{\Lambda}_t = \sum_{j=0}^{L-1} \hat{r}_{t+j} + \mathrm{E}_t \hat{\Lambda}_{t+L}. \tag{8.63}$$

By combining the latter equation with the consumption Euler equation ⟨8.12⟩, the single-interest-rate IS equation is restored, such that aggregate demand depends on the path of short-term interest rates, but neither on the long-term rate $\hat{r}_{L,t}$, nor on the risk premium Φ_t. Therefore, the fundamental result that asset prices are a function of the relative asset quantities remains intact, but this entails no further implications for the transmission of monetary policy. This clearly shows that for the portfolio balance channel to work in this model, heterogeneous agents with asymmetric attitudes towards risk must exist. More precisely, *restricted* households must have a lower risk aversion towards long-term bonds (a lower value of υ) than the *unrestricted* households who trade in both markets. Taken together, the three key modifications to an otherwise standard New Keynesian DSGE-model are:

i. heterogeneous households
ii. imperfect asset substitutability for *unrestricted* households
iii. lower degree of imperfect asset substitutability for *restricted* households.

For multiple channels of monetary policy, all three conditions have to be fulfilled simultaneously. If condition (i) or (ii) is violated, the model collapses into its single interest-rate version with $\lambda = 1$. If condition (ii) is violated, there is an exogenous term spread between the short- and the long-term rate, but monetary policy has no impact on this spread. In general, the ALSN model captures three cases which illustrate different implications for monetary policy. I will shortly discuss them below:

Baseline two-asset model ($\lambda = 1$, $\Phi_t^u = 0$) This version with homogeneous households and perfect asset substitutability was analysed in section 8.1. Here, monetary policy only operates via the conventional interest-rate channel and long-rates are the weighted sum of current and future short-rates. The aforementioned case with seemingly heterogeneous agents subject to identical costs in the long-term bond market ($\lambda = 1$, $\Phi_t^u > 0$) is essentially a sub-case of this baseline, as it implies a single interest-rate channel as well.

Exogenous interest rate differential model ($\lambda < 1$, $\Phi_t^u = 0$): This version involves a violation of condition ii. Deviations of the long-term rate from the expectations theory of the term structure are only due to the stochastic cost shock ς_t in the long-term bonds market. Since this friction is unrelated to any other macroeconomic variable, monetary policy is unable to affect the wedge between long- and short-term rates independently.

Multiple-channels model ($\lambda < 1$, $\Phi_t^u \neq 0$) In addition to the conventional interest rate channel, a portfolio balance channel exists and relative asset quantities supplied by the monetary authority matter for aggregate demand. With imperfect substitutability and heterogeneous households, there is an endogenous term premium attached to longer dated assets that monetary policy can affect by means of large-scale asset purchases, for instance.

In the last model, QE (an analogy to large-scale asset purchases) is effective, because liquidity frictions inhibit perfect arbitrage between short- and long-term assets. In combination with the assumption of heterogeneous agents, this leads to the long-term rate being a distinct part of the dynamic IS-equation. Thus, the term structure and the dynamic IS-relation are the key mechanisms through which QE and the portfolio balance channel affect economic activity. To see this more clearly, recall that the term structure under imperfect asset substitution is given by

$$\hat{r}_{L,t} = \frac{1}{L}\sum_{j=0}^{L-1}\hat{r}_{t+j} + \frac{1}{L}\left(\varsigma_t - \tau(\hat{m}_t - \hat{b}_{L,t})\right). \qquad \langle 8.64 \rangle$$

QE entails an open-market operation that reduces the supply of long-term bonds against a simultaneous increase in reserves. With respect to the yield curve, $\hat{m}_t > \hat{b}_{L,t}$ causes the endogenous term premium to fall when asset prices adjust to rebalance private portfolios (transaction costs ς_t are exogenous and beyond the control of monetary policy). Thus, a relative rise in the supply of the more *liquid* asset will lead to rising prices and declining yields of the more *illiquid* asset. In other words, QE flattens the yield curve.

Note that in this model economy only two types of government bonds exist. A more realistic framework should also consider private debt – such as corporate bonds and equities – as portfolio rebalancing tends to reduce the term premium of all longer-dated, risky securities in the economy. Rising asset prices and declining yields imply lower credit costs for firms and a positive wealth effect for households. If households react to the wealth effect by increasing consumption, or if firms invest some of the extra funding raised on capital markets, aggregate demand will increase. As mentioned above, however, an important ingredient for the portfolio balance channel to work is the presence of heterogeneous agents. Here, this is achieved by incorporating *restricted* households into the model. Since these households can only trade in long-term but not in short-term bonds, their consumption Euler equation is governed by the real long-term rate $\hat{r}_{L,t}$ only. In the aggregate, this leads to a separate role of the real long-term rate ($\hat{r}_{L,t}$) over and above the real short-term rate ($\hat{r}_{t+j}$) to play a part in the dynamic IS-equation. From ⟨8.54⟩, the latter can be written as

$$\hat{y}_t = -\frac{\lambda}{\phi_2}\sum_{j=0}^{L-1}\hat{r}_{t+j} - \frac{(1-\lambda)}{\phi_2}L\hat{r}_{L,t} + \frac{\phi_1}{\phi_2}\hat{y}_{t-1} + \frac{\beta\phi_1}{\phi_2}\mathrm{E}_t\hat{y}_{t+1}$$
$$- \frac{\phi_1}{\phi_2}\mathrm{E}_t\hat{y}_{t+L-1} - \frac{\beta\phi_1}{\phi_2}\mathrm{E}_t\hat{y}_{t+L+1} + \hat{y}_{t+L} + \left(\frac{1-\beta h\rho_a}{1-\beta h}\right)(1-\rho_a^L)\hat{a}_t. \quad \langle 8.65\rangle$$

with

$$\phi_1 = \frac{(\sigma-1)h}{1-\beta h}, \qquad \phi_2 = \frac{\sigma+(\sigma-1)\beta h^2-\beta h}{1-\beta h}.$$

In addition to the parameter τ from equation ⟨8.64⟩, the effectiveness of QE and the portfolio balance effect depends on the amount of *restricted* households $(1-\lambda)$, the discount factor β, the degree of habit persistence h, and on the household's degree of risk aversion σ.

Last but not least, it should be acknowledged that the conjecture of segmented asset markets breaks Ricardian equivalence in this model – although the fiscal rule ⟨8.35⟩ ensures that transfers react inversely to government debt. The violation of Ricardian equivalence stands in marked contrast to the benchmark world, where a risk-averse representative agent with rational expectations and unlimited access to frictionless financial markets anticipates that higher reserves today need to be financed by higher taxes (lower transfers) tomorrow. A risk-averse agent who dislikes volatility in consumption would thus not increase consumption today, since he would have to "pay" for this behavior by a lower level of consumption tomorrow. This intertemporal logic essentially summarizes the reasoning behind the irrelevance proposition for open-market operations by Wallace (1981). With absence of any form of market segmentation, a policy operation that changes the ratio between reserves and long-term bonds would affect the yield of long-term bonds but without any material effect on the real economy: *Unrestricted* households would engage in arbitrage activities such that relative equilibrium asset prices do not change, thus preventing any change in households' intertemporal consumption profile.

This is different under asset market segmentation. A change in the yield of long-term bonds implies a different expected portfolio return for the *restricted* households. This leads to a change in the *restricted* households' discount factor giving rise to an alternative intertemporal consumption allocation. General equilibrium forces then also affect the consumption expenditures of *unrestricted* households as well as production capacities of firms. In a nutshell, market segmentation leads to the non-neutrality of open-market operations, implying that the irrelevance proposition of Wallace does not hold.

8.3.2. Simulations

The simulation exercises performed in this section analyse the model's response to a contractionary monetary policy shock, a negative demand shock, and a money supply shock in case the central bank follows a simple money growth rule. The parameterization and steady state values of key variables used in the simulations are listed in Table 8.1.

Symbol	Parameter Description	Value
α	Output elasticity w.r.t. labour hours	1/3
β	Discount Factor	0.995
σ	Risk aversion	2
δ	(Inverse) elasticity of money demand	4.36
φ	(Inverse) Frisch elasticity	1.74
h	Degree of habit persistence	0.7898
δ_0	Elasticity of money demand w.r.t. adjustment costs	1.82
λ	Fraction of unrestricted households	0.9322
τ	Elasticity of long-term rate to portfolio mix	0.54
χ	Effect of habit persistence on real marginal costs	1.36
$\tilde{\lambda}$	Slope of the Phillips-Curve	0.014
ϕ_i	Interest rate smoothing parameter	0.8556
ϕ_y	Interest rate response to output gap	0.3295
ϕ_π	Interest rate response to inflation	1.6090
ϕ_μ	Interest rate response to real money growth	1.38
ρ_a	Persistence of intertemporal preference shock	0.89
ρ_e	Persistence of money demand shock	0.99
ρ_z	Persistence of technology shock	0.97
ρ_ς	Persistence of transaction cost shock to long-term bond	0.80
ρ_{b_L}	Persistence of value shock to long-term bond	0.5
i	Steady state short-term nominal rate	β^{-1}
i_L^L	Steady state long-term nominal rate	β^{-L}

Table 8.1.: Parameterization

To calibrate their model, Andrés et al. (2004) performed a maximum likelihood estimation using time series data for quarterly US real GDP, the quarterly average of the monetary base, quarterly average population, quarterly average seasonally adjusted CPI, and the quarterly average of the nominal Federal Funds rate for a period from 1980-1999. Their estimation for the discount factor equals 0.991, which amounts to an annualised steady state risk-free real rate of about 3.6%.[12] Newer estimates, however, point to a *lower* value of the annualized risk-free real rate.

The updated dataset of Laubach and Williams (2003) indicates an average real rate for the same period of around 3.1% and their results (tentatively) suggest that the real rate experienced a secular decline. Its average value declined to approximately 1.5% between 1999-2015. This finding is confirmed by Hamilton et al. (2015), who report a time varying US steady state real rate that currently lies in a range of 1%-2%. Based on this evidence, the discount factor is calibrated to 0.995, which is equivalent to an annual steady state real rate of 2% as inflation equals zero in the steady state. Since no liquidity friction is present in the steady state, the short-term nominal (real) rate equals the long-term nominal (real) rate, such that the term premium is also zero in the steady state.

Moreover, Chen et al. (2012) constructed a model based on Andrés et al. (2004) in order to measure the macroeconomic effects of the Fed's more recent large-scale asset purchase program. In their empirical analysis, they estimate the model with Bayesian methods using quarterly data for the US from the third quarter of 1997 to the third quarter of 2009. Their estimation comprises seven time series including real GDP per capita, real wages, labor hours worked, the price index of personal consumption expenditures excluding food and energy, the nominal effective Federal Funds rate, the 10-year Treasury constant maturity yield (as a proxy for long-term debt), and the ratio between long-term and short-term Treasury debt.[13] When feasible, I adopt the updated parameter values of Chen et al. (2012). Hence, households are assumed to be relatively risk averse ($\sigma = 2$) plus they show a rather strong degree of habit persistence ($h = 0.7898$).[14] The effect of habit persistence on real marginal costs, χ, is estimated to 1.36 and the output elasticity to hours worked equals 1/3. According to equation $\langle 8.42 \rangle$, this implies a value for the Frisch elasticity of 1.74. The estimated slope of the Phillips curve together with the discount factor and the assumption of a 10% steady state mark-up implies a va-

[12] Smets and Wouters (2003) as well as Galí (2008) calibrate the discount factor to 0.99. This has been a standard result in the literature, implying a slightly higher annual real rate of 4%.

[13] In contrast to the ALSN-model, Chen et al. (2012) assume the imperfect substitutability to take place not between money and long-term bonds, but between long-term bonds and short-term bonds.

[14] In the initial ALSN-model, habit persistence was estimated to be even larger, i.e. 0.9.

lue for θ of 0.74. This means that firms, on average, are able to readjust their prices every four quarters. This is a standard result for nominal price rigidity in the New Keynesian literature (Woodford, 2003, p. 212).

What is crucial for the effectiveness of the portfolio balance effect is the degree of market segmentation, measured by λ, respectively $(1-\lambda)$. Andrés et al. (2004) estimate the group of unrestricted households to be 0.3, i.e. they find a rather strong degree of market segmentation. Chen et al. (2012), however, estimate the posterior mean of λ to 0.9322, which implies a comparatively modest degree of market segmentation. A higher value of λ, however, means that more agents are subject to the liquidity friction that gives rise to the imperfect asset substitutability being responsible for the portfolio balance effect. Therefore, as will be shown below, the portfolio balance effect delivers substantially different shock responses when compared to the baseline case with homogeneous agents and perfect asset substitutability. The second important parameter that drives this result is the positive value of τ, confirming that the long-term rate reacts endogenously to relative asset stocks.[15] Moreover, the AR(1) exogenous cost shock to long-term bonds is relatively persistent (0.8). Both parameters cause substantial deviations from the expectations theory of the term structure.

The estimates of the monetary policy parameters are fairly standard. According to Chen et al. (2012), monetary policy performs a rather strong interest rate smoothing ($\phi_i = 0.8556$), reacts modestly to the output gap ($\phi_y = 0.3295$), and obeys the Taylor principle by responding overproportionally to inflation ($\phi_\pi = 1.6090$). Additionally, monetary policy shows – as in the initial ALSN-model – a significant reaction to real money growth ($\phi_\mu = 1.38$).

Figure 8.1 displays the impulse response functions to a contractionary monetary policy shock if the central bank follows the estimated interest rate rule given by equation $\langle 8.36 \rangle$. To illustrate the richer transmission mechanism for an active portfolio balance effect, Figure 8.1 compares the IRFs for both model versions presented above: the baseline model with homogeneous agents and perfect asset substitutability (solid blue line); and the model with heterogeneous agents and imperfect asset substitutability (dashed red line).

Note that the model exhibits sufficient price stickiness, such that a liquidity effect emerges, which can be inferred from the inverse movement of both nominal and real short-term rates compared to real balances. In addition to the interest rate shock, a dy-

[15] Since no directly comparable parameter to τ exists in the study of Chen et al. (2012), I stick with the estimation of Andrés et al. (2004) for this parameter.

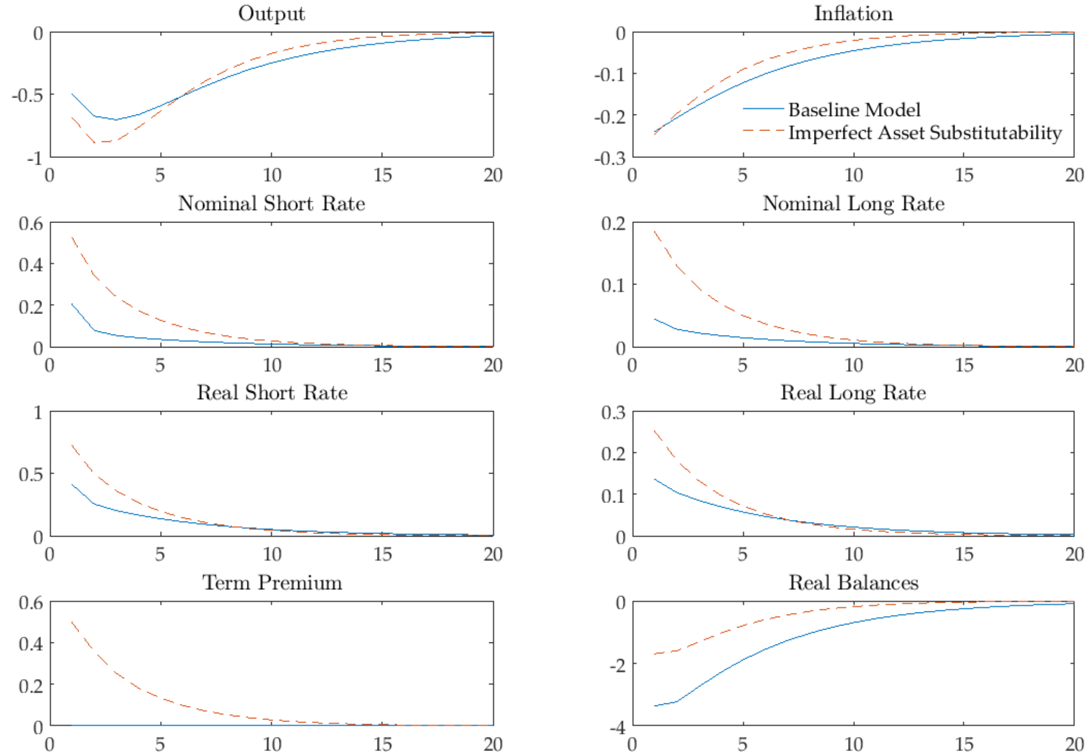

Figure 8.1.: Monetary policy shock (interest rate rule)

namic response of relative asset quantities takes place. The reduction in real balances relative to long-term bonds generates *less liquid* portfolios for unrestricted households, as both assets represent imperfect substitutes. In order to compensate this liquidity loss, both nominal and real long-term rates have to rise implying that the term premium also rises. This generates a higher drop in output (about -0.9%) and a slightly higher drop in inflation (about -0.25%), although the convergence back to the steady state happens faster than in the baseline case. In the latter case, the peak responses of output and inflation are -0.7% and -0.24%, respectively. The difference between the two models is less pronounced for inflation. For the most part, this can be explained by the relatively stronger decline of real balances in the baseline case. Moreover, since the baseline model is characterized by perfect asset substitutability, the expectations theory of the term structure holds, implying that the term premium equals zero (lower left panel in Figure 8.1).

Figure 8.2 depicts the dynamic responses for a shock to households' intertemporal preferences (a negative demand shock). A negative demand shock causes output and inflation to fall. With monetary policy following the Taylor rule of equation ⟨8.36⟩, nomi-

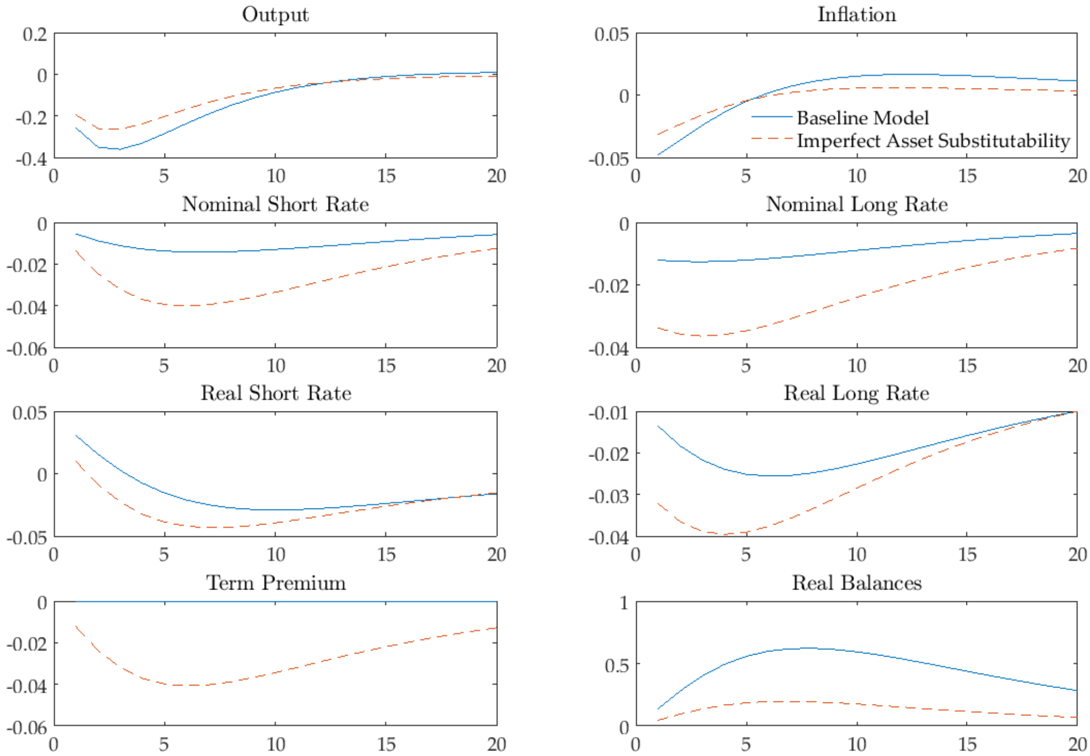

Figure 8.2.: Negative demand shock (interest rate rule)

nal short rate should *decrease*. On the other hand, since real balances rise in response to a negative demand shock (see the lower right panel in Figure 8.2), this calls for an *increase* in the Taylor rate. Ex ante, the net effect of those countervailing effects is indeterminate. But with the model calibration listed in Table 8.1, the central bank reacts to a negative demand shock by loosening its monetary policy stance. Furthermore, note that under imperfect asset substitutability, real balances rise less, contributing to a lower policy rate compared to the baseline scenario. If assets are imperfect substitutes, the relatively stronger stabilization is further amplified by a falling term premium (red dashed line in lower left panel of Figure 8.2) which stimulates output and inflation beyond the effects generated by the pure expectations theory of the term structure.

Finally, Figure 8.3 shows the effects of a positive money supply shock. The IRFs are calculated under the conjecture that the monetary policy strategy is changed to a univariate monetary growth rule,

$$\Delta M_t = \rho_M \Delta M_{t-1} + \epsilon_t^M, \qquad \langle 8.66 \rangle$$

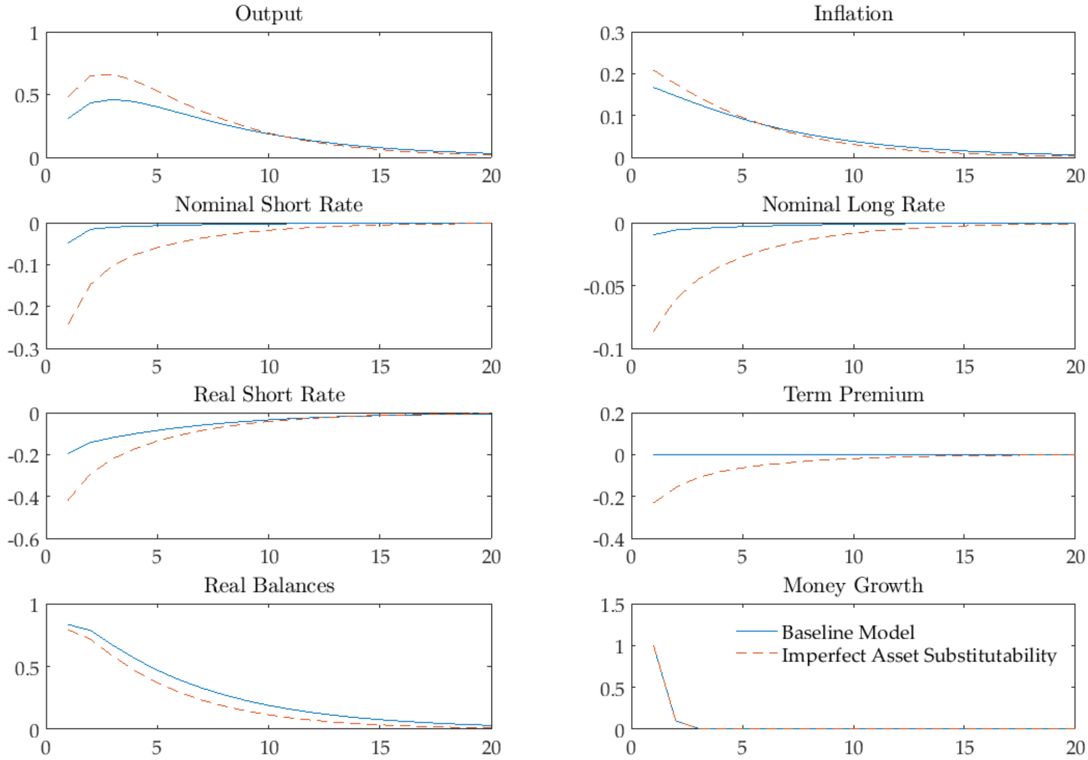

Figure 8.3.: Monetary policy shock (money growth rule)

with $\rho_M \in [0, 1)$ and ϵ_t^M as a white noise monetary supply shock.[16] Given $m_t = M_t/P_t$, the identity

$$m_t \equiv m_{t-1} - \pi_t + \Delta M_t. \quad \langle 8.67 \rangle$$

establishes a positive relation between real balances (m_t) and nominal money growth (ΔM_t) and the sluggishness in the adjustment of prices ($\theta = 0.74$) implies that, when monetary policy boosts the money supply, real balances also rise. Equilibrium in the money market thus requires that either output rises or the nominal interest rate falls. Besides a liquidity effect, Figure 8.3 reveals that the short-term real rate declines more strongly than the nominal rate (due to increasing inflation expectations), which stimulates aggregate demand. So far, the adjustment process to an expansionary monetary growth shock does not vary from the baseline NK model. In addition, however, the simulations replicate the portfolio balance channel of quantitative easing: The injection of additional reserves induces the ratio of money to long-term bonds to rise. As this cushions the costs associated with the liquidity friction in the long-term bond market,

[16] The persistence of the money supply shock was set to 0.5 in the simulations that produced Figure 8.3.

the term premium declines, causing output and inflation to rise above the level of the baseline model.

The money growth shock in Figure 8.3 serves as a proxy for QE but goes only halfway in explaining all of the effects taking place during "real world" large-scale asset purchases. In the model's analysis, monetary policy only injects reserves, but does not reduce the stock of long-term bonds in the hands of the public. Allowing for the latter would lead to an even larger increase in the money-bond ratio, which would further amplify the portfolio balance effect. But there are additional aspects of QE the model conceals. If the policy rate is constrained by the zero lower bound, for instance, the effectiveness of QE increases substantially. Furthermore, large-scale asset purchases may serve as signaling device that can help to overcome time-inconsistency issues attached to forward guidance. By constructing a richer model that incorporates some of those additional channels, one could reasonably suspect to find a bigger impact of central bank large-scale asset purchases. This will be done in the following section.

8.4. Model Extensions: ZLB and Financial Intermediaries

In response to the economic slump that followed the failure of Lehman Brothers, central banks around the globe lowered their short-term policy rates towards the ZLB. With the interest rate policy thereby largely exhausted, central banks increasingly turned towards large-scale asset purchases programs. Drawing in large parts on the model by Harrison (2012), the following section thus analyzes the dynamics of such LSAPs by including financial intermediaries and the zero lower bound of the short-term policy rate.

8.4.1. Key Aspects of the Model

In the model, financial intermediaries issue demand deposits and hold government bonds of different maturities. Hence, financial intermediaries perform maturity transformation for the government, but they do not extend loans to private businesses. Although this simplification may disguise central aspects of financial intermediaries, it seems justified in this particular context, as it helps to highlight the key mechanism of the portfolio balance effect.

Financial Intermediaries Thus, in this specific framework, a representative financial intermediary maximizes the profit function

$$\max E_t \left[i_t B_t + i_{L,t+1} B_{L,t} - \left(i_t^A A_t + \frac{\tilde{\upsilon}}{2} \left(\frac{B_t}{B_{L,t}} \tilde{\eta} - 1 \right)^2 P_t \right) \right] \tag{8.68}$$

subject to the balance sheet constraint

$$B_t + B_{L,t} \equiv A_t. \tag{8.69}$$

Profits are equal to the difference between the returns on the respective bond holdings ($i_t B_t + i_{L,t+1} B_{L,t}$) and the returns paid to household deposits ($i_t^A A_t$) minus portfolio adjustment costs. Short-term bonds (B_t) are one-period zero-coupon bonds with i_t as their nominal return and long-term bonds are modeled as consols ($B_{C,t}$).[17] With V_t as the price of consols, their value in period t is defined as

$$B_{L,t} = V_t B_{C,t} \tag{8.70}$$

and the ex post return $i_{L,t}$ is given by

$$i_{L,t} = \frac{1 + V_t}{V_{t-1}}. \tag{8.71}$$

That is, financial intermediaries aim at a profit maximizing portfolio mix which is determined by the relative returns on government bonds. Introducing portfolio adjustment costs into financial intermediaries' profit function implies that short- and long-term bonds are imperfect substitutes – and that increasing the portfolio share of one type of bond increases the value of the other. This assumption is based on the notion that financial intermediaries demand more relatively illiquid assets if they have ample holdings of liquid assets (and vice versa). Although the functional form of the liquidity friction (the squared term in equation ⟨8.68⟩) is similar to the ALSN model, note the difference to the ALSN-model here: In the latter, adjustment costs accrue on the part of households if they shift between money and long-term bonds, while in this model they are based on the portfolio mix between short- and long-term bonds on the balance

[17] Modeling long-term bonds as consols has the convenient advantage that, although they can be traded each period, their optimal portfolio share depends on their one-period return only. In the ALSN-model, the exclusion of a secondary market for long-term bonds yields a similar result, but this assumption may seem rather unrealistic.

sheet of the financial intermediary. Other than that, the parameters follow the logic of the ALSN-model. The degree of imperfect asset substitutability depends on $\tilde{\upsilon}$: greater values of $\tilde{\upsilon}$ imply higher costs if the portfolio mix deviates from its steady-state value $\tilde{\eta}$.[18] The result is that the expected market yield on long-term bonds is a function of the short-term rate and the portfolio mix of financial intermediaries[19]

$$\hat{i}_t = \hat{i}_{L,t+1} + \frac{\beta\tilde{\upsilon}(1+\tilde{\eta})}{b_L}\left(\hat{b}_t - \hat{b}_{L,t}\right) \quad \langle 8.72\rangle$$

As a consequence, the return households receive on their banking deposits is a weighted average of market yields on short- and long-term government bonds, i.e.

$$\hat{i}_t^A = \frac{1}{1+\tilde{\eta}}\hat{i}_t + \frac{\tilde{\eta}}{1+\tilde{\eta}}E_t\hat{i}_{L,t+1}. \quad \langle 8.73\rangle$$

This is relevant, since households' Euler equation includes the deposit rate i_t^A:

$$\hat{y}_t = E_t\hat{y}_{t+1} - \frac{1}{\sigma}\left[\hat{i}_t^A - E_t\hat{\pi}_{t+1} - r_t^n\right]. \quad \langle 8.74\rangle$$

Hence, aggregate demand is negatively related to the deposit rate stemming from financial intermediaries' optimization calculus. Ultimately, however, the deposit rate in equation ⟨8.73⟩ just mirrors the combined effects of a *conventional*, Taylor-type interest rate policy

$$\hat{i}_t = \phi_i\hat{i}_{t-1} + (1-\phi_i)\left(\phi_\pi\hat{\pi}_t + \phi_y\hat{y}_t\right) + \epsilon_{i_t}, \quad \langle 8.75\rangle$$

together with the *unconventional* asset purchase policy,

$$b_t^{cb} = q_t b_{L,t}^g, \quad \langle 8.76\rangle$$

where q_t denotes the fraction of long-term government debt the central bank chooses to hold. To simplify the analysis, the stock of long-term bonds (b_C) is held fixed, i.e.

$$b_{L,t}^g = \bar{b}_C V_t, \quad \langle 8.77\rangle$$

such that the value of long-term bonds only varies with the price V_t. Notice that the price itself ultimately depends on developments in the economy. The bond market clearing

[18]With $\tilde{\eta} = B_L/B$, adjustments costs are zero in the steady-state.

[19]Lower case letters are nominal variables divided by the price index. See Appendix B.6.1 for a detailed derivation

condition is thus given by

$$b_{L,t} = (1 - q_t) b^g_{L,t} = (1 - q_t) \bar{b}_C V_t, \tag{8.78}$$

where $b_{L,t}$ is the amount of long-term bonds in the hands of the financial intermediaries. The short-end of the bond market on the other hand depends on the transfer payments to households, which obey the rule

$$\frac{\tau}{b} \hat{\tau}_t = -\frac{\theta_\tau \hat{i}_{t-1} \hat{b}_{t-1}}{\beta}. \tag{8.79}$$

Here, θ_τ measures the elasticity of transfer payments with respect to the financing costs of previously issued debt. As financing costs rise, transfer payments are reduced. This ensures the dynamic stability of government debt.[20] In accordance with the recent experience of large-scale asset purchase programs, public asset purchases are financed via money creation and occur only in the long-term government debt market. The balance sheet effect for the central bank is thus given by

$$\Delta_t = m_t - m_{t-1} - \left[b^{cb}_t - i_{L,t} b^{cb}_{t-1} \right]. \tag{8.80}$$

The above information can be used to construct the *consolidated* government budget constraint in terms of the one-period return on consols. As above, lower case letters denote nominal variables deflated by the price index and $\tau_t = T_t / P_t$. Therefore, the consolidated government is subject to

$$b^g_{L,t} + b_t - i_{L,t} b^g_{L,t-1} - i_{t-1} b_{t-1} + \Delta_t = \tau_t. \tag{8.81}$$

Real transfers are financed either via bond issuance or via money creation by the central bank.

Households and Firms As the the optimization of the household and firm sector follows the standard approach of the New Keynesian Model, the respective derivations are moved to the appendix B.6.1.

Monetary Policy Implications What matters more in this context is that by extending the ALSN-framework by a rudimentary banking sector, the present model is able to drive a wedge between the long-term interest rate and the sequence of short-term rates,

[20] In the simulation below, the value of θ_τ is chosen accordingly.

without having to assume limited participation or heterogeneous agents among households. To be precise, the relatively ad hoc friction of the ALSN-model – adjustment costs in household's utility function – is shifted to financial intermediaries cost functions. In this vein, the model can explicitly account for *two separate* policy instruments at the disposal of the central bank. Firstly, *conventional* monetary policy is implemented by adjusting the short-term policy rate (i_t). Secondly, *unconventional* monetary policy is conducted by varying the fraction of long-term bonds held on the central bank's balance sheet (q_t).

8.4.2. Simulations

In the following, I discuss some model simulations using the parameterization presented in Table 8.2. By assumption, real money balances represent a small fraction of short-

Symbol	Parameter Description	Value
β	Discount Factor	0.9925
σ	Risk aversion	0.157
δ	(Inverse) elasticity of money demand	6
κ	Slope of the Phillips-Curve	0.024
ϕ_i	Interest rate smoothing parameter	0.85
ϕ_y	Interest rate response to output gap	0.5
ϕ_π	Interest rate response to inflation	1.5
ρ_a	Persistence of intertemporal preference shock	0.5
ρ_q	Persistence of asset purchase shock	0.95
m/b	Steady-state ratio of money to short-term bonds	0.001
γ	Steady-state ratio of long-term to short-term bonds	3
$\tilde{\upsilon}$	Elasticity of long-term rate to portfolio mix	0.1
θ_τ	Feedback parameter in transfer rule	0.025

Table 8.2.: Parameterization

term bonds ($m/b = 0.001$), but long-term bonds outweigh short-term bonds (γ) by a factor of three in the steady-state (as estimated by Kuttner (2006) for US data). Following Harrison (2012), the feedback parameter in the transfer rule is relatively small ($\theta_\tau = 0.025$) in order to ensure that shocks to the level of short-term bonds are not immediately offset by adjustments in transfers. The coefficients of the interest rate rule follow the standard calibration of Taylor (1993). Furthermore, the baseline calibration for the elasticity of long-term bond rates with respect to the portfolio mix of financial intermediaries ($\tilde{\upsilon}$) is set to 0.1. This estimation lies in the middle between the value proposed by Andrés et al. (2004), which in this model corresponds to a value of around 0.045, and that of Bernanke et al. (2004), who suggest the elasticity to lie at around 0.25. The value of the parameter for relative risk aversion ($\sigma = 0.157$) equals the benchmark estimation of Rotemberg and Woodford (1997), implying an intertemporal elasticity of substitution of around 6. Note that this value for interest-elasticity is relatively high compared to the ALSN-calibration (see Table 8.1). However, as Levin et al. (2010) show, interest-elasticity must be sufficiently large (at least 6) for 'Great-Recession'-style demand shocks to produce a binding ZLB within the canonical NK model.

Figure 8.4 depicts the IRFs for a negative demand shock ($\epsilon = -1$) where the annual natural rate drops by 2%.[21] At first, to highlight the effects of the ZLB, it is assumed that short- and long-term bonds are perfect substitutes ($\tilde{\upsilon} = 0$), that means QE ceases to play any role in stabilizing the economy. With zero steady-state inflation, sticky prices and an unbounded policy rate, monetary policy can only generate a fall in the short-term real rate if the policy rate is lowered into negative territory (solid blue lines in Figure 8.4). If that is the case, annual inflation actually increases and output falls only modestly, despite the relatively strong demand shock. Things look quite different, however,

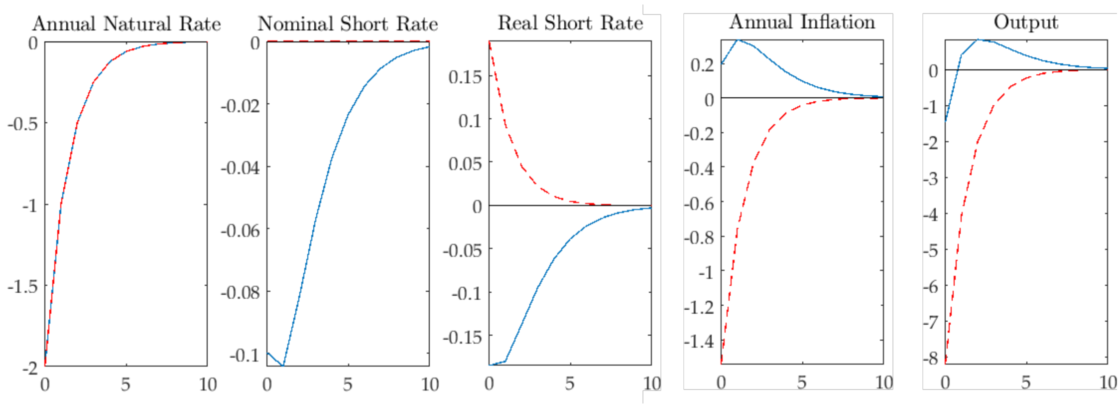

Figure 8.4.: Demand shock with binding ZLB ⋄ Red dashed lines depict IRFs with binding ZLB; blue solid lines depict IRFs with unbounded policy rate

if the zero lower bound is imposed on the policy rate (red-dashed lines in Figure 8.4). In the simulation exercise, the ZLB is assumed to bind for 10 periods.[22] Without the expansionary interest-rate stimulus, the negative demand shock has a substantially bigger

[21] With $\rho_a = 0.5$, this shock is also quite persistent.

[22] The model is simulated with Dynare (Adjemian et al., 2014) and the algorithm for simulating the ZLB is based on Holden and Paetz (2012) as well as Holden (2011). The codes are available upon request.

impact on inflation and output. This simulation exercise underlines the potential of QE as an additional monetary policy tool.

At the same time, however, it should be noted that the portfolio balance effect reduces the effectiveness of *conventional* interest rate policy – especially when the short-term policy rate is *not* bounded. The reason for this is simple: In a conventional open market operation, a central bank buys short-term bonds in exchange for reserves. As a consequence, aggregate liquidity increases and the entire yield curve shifts downwards. This channel is active in the model under consideration. Alongside that mechanism, however, is the portfolio balance effect arising from desired portfolio mix between short- and long-term bonds on financial intermediaries' balance sheets. A conventional open market operation reduces the level of publicly available short-term bonds for two reasons: First, because of the quantity effect of a conventional open-market operation (described above); and second, because of the supply effect induced by the government's budget constraint. With a fixed supply of long-term bonds, a lower policy rate leads to a reduction in debt financing costs for the government. Other things equal, this will lead to a lower issuance of short-term government debt. Thus, the portfolio allocation of financial intermediaries shifts towards long-term bonds, which, according to equation ⟨8.72⟩, implies that the premium on long-term bonds must rise. Overall, the net effect of this process is that average interest rate falls by less than the short-term policy rate.

Figure 8.5 illustrates this point for a conventional monetary policy shock under different degrees of the portfolio balance effect (captured by different values of $\tilde{\upsilon}$): For $\tilde{\upsilon} = 0$ (blue-solid lines), we are back in the standard NK model where bonds are perfect substitutes and no portfolio balance effect is present. The IRFs for $\tilde{\upsilon} = 0.1$ (red-dashed lines) depict the baseline case with a moderate portfolio balance effect; whereas the yellow-crossed lines show the responses if the portfolio balance effect is most pronounced ($\tilde{\upsilon} = 0.3$). Interestingly, the higher the degree of the portfolio balance effect, the sharper the decline in the policy rate (upper-left panel in Figure 8.5). But irrespective of this relatively sharp (and persistent) decline in the policy rate, the five-year spot rate falls by less, the higher the costs are associated with the imperfect substitutability between short-and long-term bonds. In fact, if the portfolio balance effect is sufficiently strong ($\tilde{\upsilon} = 0.3$), the five-year spot rate actually increases after 3 periods. As a consequence, the reaction of output and inflation to a conventional monetary policy shock is inversely related to the degree of the portfolio balance effect.

In the same manner, Figure 8.6 shows the model's response to an asset purchase shock under different degrees of the portfolio balance effect, given an unbounded policy rate.

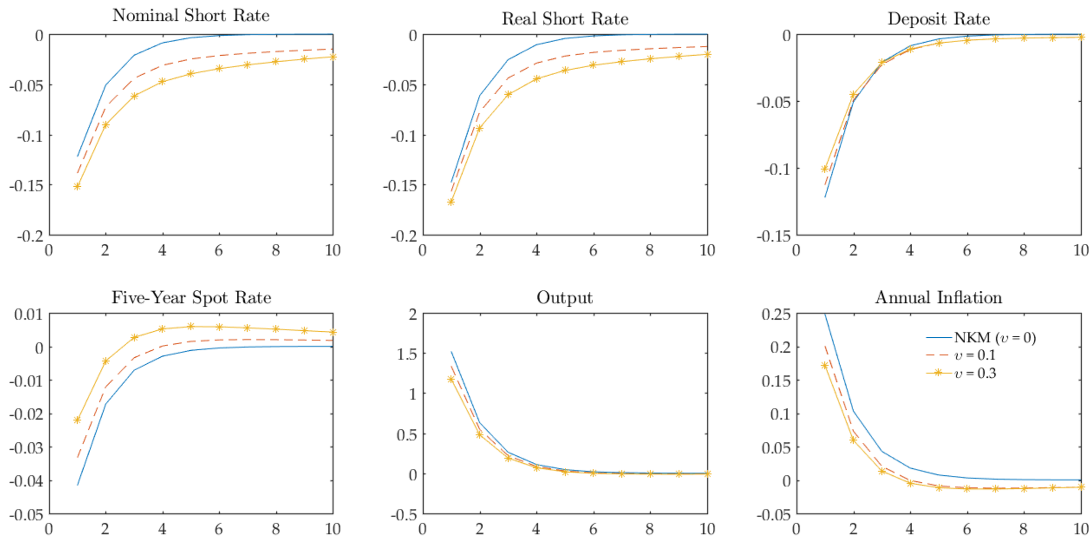

Figure 8.5.: Conventional monetary policy shock

Here, it is assumed that the central bank buys up 25% of the outstanding stock of long-term government debt. This number is a rough estimate of the expanded public sector asset purchase program undertaken by the ECB.[23]

As expected, central bank asset purchases have an expansionary effect on output and inflation that increases in $\tilde{\upsilon}$.[24] However, if monetary policy mechanically obeys to its Taylor-Rule ⟨8.75⟩, the expansionary effect on output and inflation is partially offset by a rising short-term rate (upper-central panel in Figure 8.6). Of course, increasing the policy rate in parallel to an expansionary asset purchase program represents a self-defeating measure that is unlikely to happen in practice. Therefore, the simulated effects in Figure 8.6 are significantly lower than most empirical studies of recent asset purchases suggest. Thus, Figure 8.7 depicts simulations (with $\tilde{\upsilon} = 0.3$) for both, the bounded and non-bounded case. As shown by the red-dashed lines in Figure 8.7, the effect of large-scale asset purchases on output and inflation more than doubles if the policy rate is bounded.

[23] It is also broadly in line with the scale of asset purchases undertaken by the BoE between 2009 and 2010. According to Joyce et al. (2011a), the BoE's total uptake of £200 billion amounts to approximately 30% of total outstanding stock of eligible long-term sovereign debt.

[24] As noted above, for $\tilde{\upsilon} = 0$, asset purchases have no effect on the economy since short- and long-term bonds are perfect substitutes.

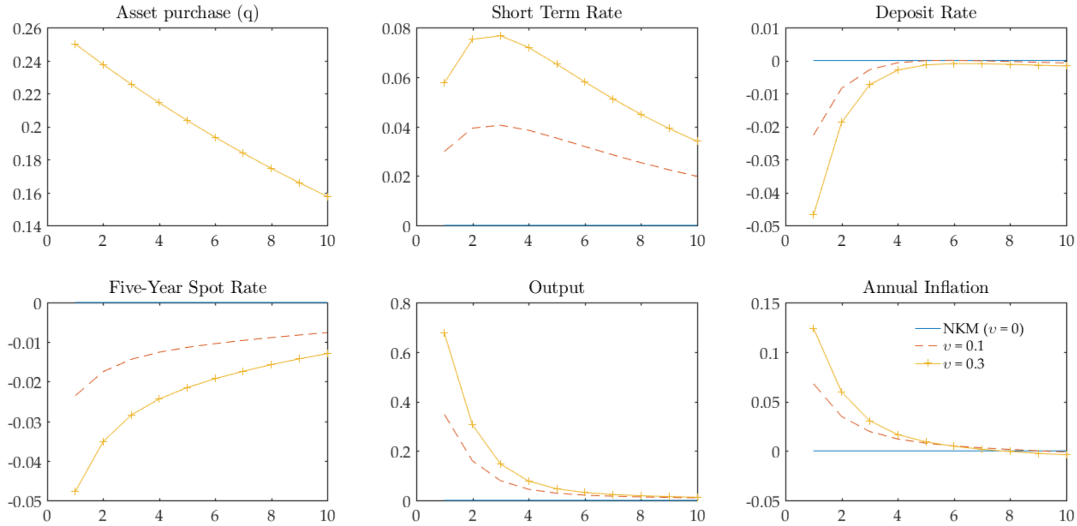

Figure 8.6.: Asset purchase shock with unbounded policy rate

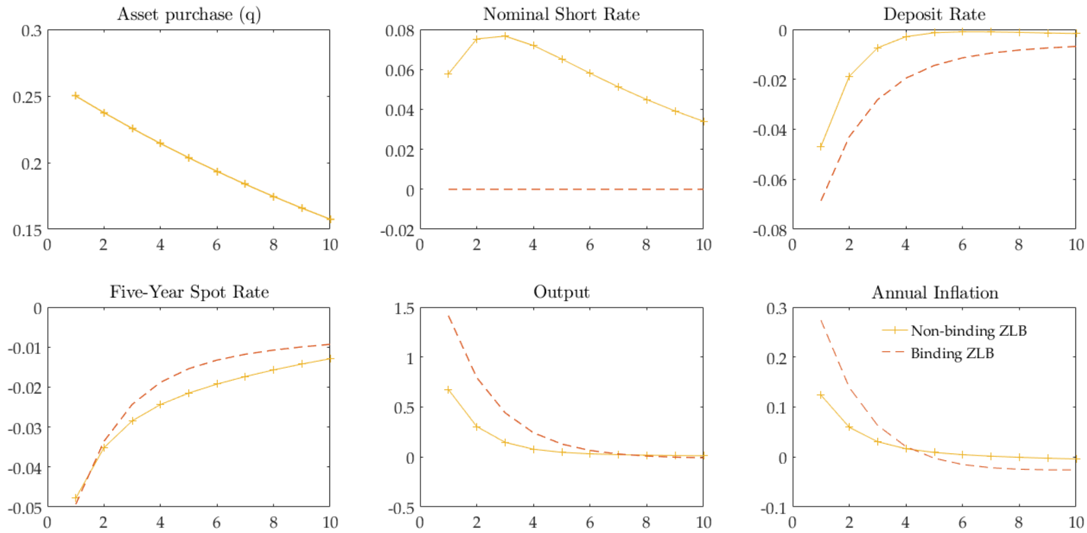

Figure 8.7.: Asset purchase shock with bounded policy rate

8.4.3. Concluding Remarks

Given the prevalence of the portfolio balance effect, this chapter provides a detailed discussion of this effect in a modern DSGE set-up. By drawing on earlier insights from the preferred-habitat theory (see section 4.2), the ALSN model highlights the macroeconomic implications of market segmentation and limits to arbitrage for the effectiveness of unconventional monetary policies.

Furthermore, the extended model of section 8.4 emphasizes the potential of large-scale asset purchases as an additional tool for monetary policy; particularly if conventional monetary policy is constrained by the zero-lower bound. Finally, the simulations of this chapter should not be interpreted as exact quantitative evidence for the effectiveness of outright monetary transactions. Instead, they serve as a mere qualitative validation for the theoretical predictions of their effects. Hence, the next chapter provides a detailed review about the macroeconomic effects of unconventional policies.

9. Empirical Evidence on Macroeconomic Effects

In comparison with the vast evidence on the financial market effects of large-scale asset purchases, only a few studies have addressed the macroeconomic implications of theses purchases. To a large extent, this reflects the greater difficulties of estimating these effects. In principle, however, three approaches are possible to capture the macroeconomic effects of unconventional asset purchases by the central bank.[1]

9.1. Classification of Estimation Methods

9.1.1. VAR-based Methods

At one end of the spectrum, there are Vector Autoregression (VAR) models. These models are essentially systems of simultaneous difference equations that impose no a priori restrictions on the structure of endogenous variables. In the sphere of monetary policy, VAR models are thus typically praised for providing a theory-free method to evaluate economic relationships (see, e.g., Sims, 1980). With respect to unconventional monetary policies, this means one could estimate for example how changes in size and/or composition of the central bank's balance sheet affect output and inflation. In fact, there are a number of studies that applied VAR models and found positive evidence for the effectiveness of unconventional monetary in the desired direction (see Figure 9.1).

However, especially during crisis times, a crucial drawback of such studies is that the relationships between the estimated variables are highly unstable or might even exhibit structural breaks. For instance, once the money market becomes satiated with reserves, the decoupling principle indicates that the previously established tight link between the policy rate and the supply of reserves will vanish. VAR models with time-series samples covering pre-crisis periods are therefore particularly problematic for estimating the effects of unconventional balance sheet policies, because the patterns that could be observed prior to the adoption of these policies are bound to change following their

[1] This classification draws mainly on Borio and Zabai (2016) and Bundesbank (2016b).

implementation.[2] Thus, the results of such data-driven approaches must be interpreted with great caution.

9.1.2. DSGE-based Methods

The other alternative to estimate the macroeconomic effects of unconventional monetary policies is to follow a more theory-based approach, mostly in the form simulating DSGE models. In contrast to VAR-models, however, these type of models are not directly applied to the data. Instead, the model's key parameters are calibrated based on other information, as for example illustrated by the parameterization of the DSGE model in chapter 8. In this respect, however, it should be acknowledged that this calibration or 'moments matching' is typically tailored to match the stylized facts of the macro variables of interest. Thus, at the current juncture, no general agreement has emerged on how to estimate the macroeconomic effects of asset purchase programs. Nevertheless, the currently used theory-based approaches can be roughly divided into *one-step* and *two-step procedures*.

9.1.2.1. One-Step Procedure

Models that follow the one-step procedure try to simultaneously estimate the effects of asset purchase programs on interest rates and the resulting macroeconomic developments. Besides the model in chapter 8, which assumed some kind of market segmentation to generate a non-neutral impact of asset purchases, generally two other approaches are feasible. At the moment, a popular approach is to incorporate a principal agent problem between banks and households to motivate a role for the bank capital channel in a modern DSGE framework. If a bank's loan supply is restricted by its equity position, the valuation effect of asset purchases will boost bank equity and facilitate lending (see section 7). Ceteris paribus, this will ultimately lead to higher aggregate demand and inflation. A widely recognized study that follows this route is the one by Gertler and Karadi (2013).

[2] To take account of this criticism, Gambacorta et al. (2014) estimate a cross-country panel VAR for a time-series sample from January 2008 until June 2011 (the post-crisis period). Thus, for the economies of Canada, the euro area, Japan, Norway, Sweden, Switzerland, the United Kingdom, and the United States, they find that the expansionary unconventional monetary policy shocks led to a significant but temporary effect on output and prices. Moreover, they find that the output response is qualitatively similar to those of conventional policy shocks (e.g. Christiano et al., 1999), while the inflation effect seems to be less persistent and weaker.

An alternative approach to model the portfolio balance effect is to assume that households are subject to funding restrictions. This may lead to additional feedback effects from asset purchases (see, e.g., Kühl, 2014; Carlstrom et al., 2014.)

Irrespective of the modeling strategy, however, due to the moment matching of DSGE models one has to admit that the results of the simulation exercises are primarily intended to shed light on the transmission channels of QE. They should not be taken as actual quantitative evidence for the size of these effects. Nevertheless, the one-step direct approach allows to study the macroeconomic effects of asset purchases consistently within a single model. In that way, the qualitative simulation results can set the stage for more refined empirical work.

9.1.2.2. Two-Step Procedure

The two-step (indirect) procedure lies somewhere in between the purely data-driven VAR approach and the one-step DSGE approach. With this procedure, the effects of asset purchases on financial variables are initially estimated by the use of 'auxiliary' econometric models. In a second step, these estimations are mapped into more traditional variables or shocks, which are then fed into a model (e.g. time series models, DSGE models) to determine the effects on the macroeconomy. Thus, when this procedure is used, the interest rate effects of unconventional monetary policies are *not* determined within the model.[3]

For example, a number of recent studies have tried to measure the stance of monetary policy at the ZLB by mapping unconventional balance sheet policies into a synthetic 'shadow' policy rate (Bullard, 2012; Krippner, 2013a; Wu and Xia, 2016),[4] but the estimated shadow rates vary considerably across the different models (see also Bauer et al., 2012b; Christensen and Rudebusch, 2014). Therefore, the reliability of the method is crucially dependent on the quality of the mapping. In particular, similar to the VAR-based approach, the decoupling principle of the floor system largely undermines attempts to infer a robust shadow rate from the size and/or composition of the central bank balance sheet.

Based on these caveats, Borio and Zabai (2016, p. 24) conclude that estimates of the macroeconomic impact of asset purchases "have to be taken with more than a pinch of salt." In a nutshell, the fundamental problem of the more data-dependent methods is

[3]See, e.g., Fuhrer and Olivei (2011) and Baumeister and Benati (2013).
[4]The shadow rate concept goes back to Black (1995).

that they rely heavily on unreliable extrapolation from previous relationships, whereas the more theory-based methods primarily illuminate the transmission mechanisms at work.

9.2. Overview of the Empirical Evidence

The comparability of the existing empirical evidence is limited somewhat by the variety of methods used in the literature. Nevertheless, the present section assembles some of this evidence, and although each individual estimate is still subject to considerable uncertainty, such an overview should at least give a hint towards the macroeconomic effectiveness of asset purchase programs.

The size of the various LSAPs by the Fed equaled about 25% of US GDP (as of 2015). To put that into perspective, the volume of asset purchases by the BoE equaled about 18% of UK GDP, whereas the ECB's initial extended asset purchase program represented about 17% of euro area GDP in 2015. Based on these broadly similar volumes, it seems surprising that the ECB's purchase program had a significantly smaller impact on output and inflation than those in the UK and the US (see Figure 9.1).

9.2.1. Euro Area

Nevertheless, the evidence suggests that QE in the euro area did have expansionary effects on output and inflation. In particular, the estimates for real GDP range from around 0.2 to 1.3 percentage points, while the impact on inflation is located in a corridor between 0.36 and 1.45 percentage points (see the left panel in Figure 9.1). These figures are calculated as the three-year average for the period between 2015-2017. While the individual results display a substantial dispersion due to the different estimation methods, taking a simple average of output and inflation across all studies delivers a value of about 0.8 and 0.7, respectively. Hence, this 'meta study' suggests that the ECB's asset purchase program as announced in January 2015 will increase euro area GDP and inflation by 0.8% respectively 0.7% over the course of 2015-2017.

9.2.2. UK and USA

The estimated output and inflation effects in the UK and the US are considerably larger than the corresponding euro area estimates. To a great extent this might be explained

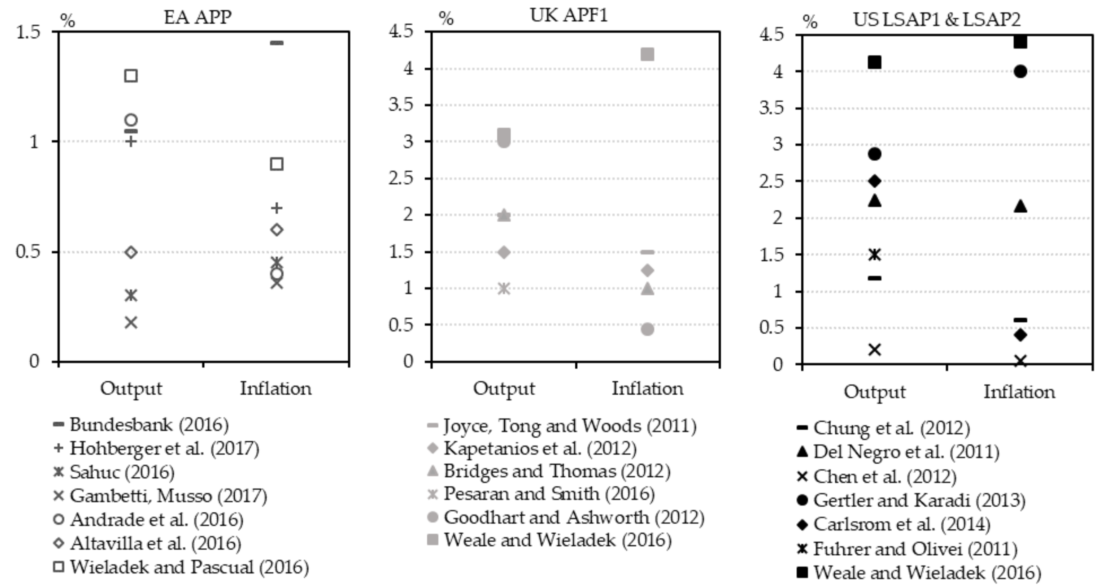

Figure 9.1.: Macroeconometric evidence for asset purchase programs ⋄ Peak estimates ⋄ Euro area studies take the announced purchase volume as of January 2015 ⋄ US studies are scaled to $1 trillion; UK studies are scaled to £200 billion ⋄ *Source:* Own illustration based on cited studies

by the different timing of the asset purchases. While the BoE and the Fed initiated their first rounds of QE promptly after the outbreak of the financial crisis (i.e. in 2008-09), the ECB adopted QE only in 2015, that is under more normal market conditions (cf. the discussion on the cyclical effectiveness of QE in chapters 4 and 5).

For the Fed's programs, the estimates lie in a range between 0.2%-4.1% for real GDP and 0.1%-4.4% for inflation, while the corresponding estimates for the BoE's asset purchases point to a corridor of 1%-3% and 0.4%-4.2%, respectively. Again, taking the mean of the individual estimates suggests that QE in the US stimulated real GDP and inflation by about 2.1% and 1.9%, which is quite similar to the UK experience (2.1% and 1.7%).

9.2.3. Concluding Remarks

Besides the differences in timing, the rather weak response of the euro area economy is likely related to the specific problems of the currency union. While at the disaggregated level most euro area countries benefit from unconventional monetary policies, they do so with a substantial degree of heterogeneity. Concerning the macroeconomic effectiveness, it seems that euro area members with less fragile banking systems benefit the most from unconventional monetary policies (Burriel and Galesi, 2016). This lends further support to the hypothesis that, ideally, unconventional monetary policies should be accompanied by fiscal measures to stabilize the banking system (e.g. via equity injections).

10. Exiting Unconventional Monetary Policies

At some point, the exit from current ultra expansionary monetary policies must take place. On the one hand, because constantly supplanting private financial markets with central bank intermediation reduces welfare due to inefficient resource allocation (Furfine, 2001; Hoerova and Monnet, 2016). On the other hand, because improving economic conditions may ultimately warrant a tighter monetary policy stance to safeguard price stability. Hence, the following section tries to shed some light on the question when and how the US and the euro area should exit from unconventional monetary policies. Then, the broad principles and the potential costs of exiting will be discussed.

10.1. Are We Ready Yet?

Key Aspects At the current juncture, policy makers are confronted with essentially two deliberations, i.e., when to *stop easing* and when to *start tightening*. The first involves the decision to stop the expansion of the central bank's balance sheet by 'tapering' its periodic asset purchases.[1] By contrast, tightening involves raising the short-term policy rate and/or contracting the central bank balance sheet. And although both decisions should be primarily dependent on economic and financial conditions, the criteria for 'tapering' and 'tightening' might differ to some extent (see, e.g., Kohn, 2013).

Specifically, balance sheet expansions should be tapered off only if the economic recovery has gained sufficient momentum such that the reversion of output and inflation can be maintained without the extra policy stimulus. On the other hand, especially after deep recessions, monetary policy should be tightened only if without such an action, output will overshoot potential and inflation will rise above its target on a sustained basis. In light of the subdued economic recovery that followed the financial crisis of 2008-09 as well as the European debt crisis of 2011-13 central bankers should therefore rather lean towards the risk of exiting too late instead of exiting too early – even if this entails a

[1] The Fed stopped its monthly large-scale bond purchases in October 2014, while the ECB currently intends to continue its purchases at least until December 2017.

temporary overshoot in inflation. Strategically, this could be achieved by placing some independent weight on the output objective in a monetary policy rule. In this setting, the dual mandate of the Fed seems to be more suitable for a flexible exit than the ECB's sole focus on price stability. Taken at face value, the latter requires the ECB to tighten its monetary policy stance as soon as inflation in the euro area reaches two percent, even if that entails that output and employment remain below their potentials for an extended period of time.

More importantly, however, such an *easing bias* should not jeopardize financial stability. In fact, the unwinding of expansionary policies might be increasingly dependent on financial market conditions. In this context, the effects of a late exit might be twofold: on the one hand, it can contribute to the buildup of asset price bubbles, while, on the other hand, the protracted economic expansion can enhance the resilience of the financial system through higher capital buffers and lower credit risk.

The Situation in the US As depicted in the upper left panel of Figure 10.1, the unemployment rate in the US has been on a steady downward path since 2010. In addition, both the production index as well as real GDP show a persistent recovery of the US economy. In contrast, the trajectory of US headline inflation fluctuated rather strongly around the Fed's inflation target of 2% (see the lower left panel in Figure 10.1). As can be inferred from the stable core inflation, this must have been mostly driven by volatile food and energy prices. Since 2015, however, headline inflation has also ascended towards its target level, while inflation expectations remained firmly anchored.

Consequently, the Fed terminated its large-scale asset purchases in October 2014, but did not raise its target range for the federal funds rate to 0.25-0.50% before December 2015. Since then, the FOMC has initiated three more rate hikes and the target range stands now at 1.00-1.25% (see the left panel in Figure 10.2). Note that, although the Fed is still reinvesting the proceeds from maturing securities in order to keep its balance sheet size constant, the shadow rate in Figure 10.2, which quantifies the stance of monetary policy at the zero lower bound, suggests that some modest tightening took place already in 2014.[2] A possible explanation is that the Fed was running down other unconventional measures during this period. However, based on the Taylor prescription

[2]In the Wu-Xia model, similar to Black (1995), the short-term interest rate is the maximum of the shadow federal funds rate and a lower bound calibrated to 0.25 basis points. This lower bound is chosen because it equals the rate the Fed paid on both required and excess reserves during the period between December 2008 and December 2015, when the FOMC set the target range for the federal funds rate to 0-0.25%. Therefore, the shadow rate is not displayed from December 2015 onwards, when the FOMC raised the target range to 0.25-0.50%. In a nutshell, the shadow rate is assumed to be a linear function of three

for the short-term policy rate, the Fed's policy stance is still too expansionary, given the current economic environment. In fact, according to the estimated Taylor rate in Figure 10.2, the FOMC should raise the effective federal funds rate by about 95 basis points to 1.9%.

The Situation in the Euro Area Despite the recent uptake in average growth, the euro area economy is still lagging behind the US recovery. This becomes most evident when looking at the euro area unemployment rate in the upper right panel of Figure 10.1. Similarly, headline inflation and especially core inflation as well as inflation expectations are still trending below the ECB's target level. At the current juncture, these indicators suggest that an exit from unconventional monetary policies would be premature. In accordance, markets widely believe that in the fall of 2017, the ECB will announce some modest tapering of its monthly asset purchases for the beginning of 2018. And in fact, the shadow rate plotted in the right panel of Figure 10.2 still indicates a substantial degree of monetary accommodation in the euro area. Thus, while the US economy appears to be ready for a further interest rate step in 2017, in the euro area, raising policy rates and an exit from unconventional policies should not be expected before the end of 2018.

latent variables called factors, which follow a VAR(1) process. The latent factors and the shadow rate are estimated with the extended Kalman filter (for further details, see Wu and Xia, 2016).

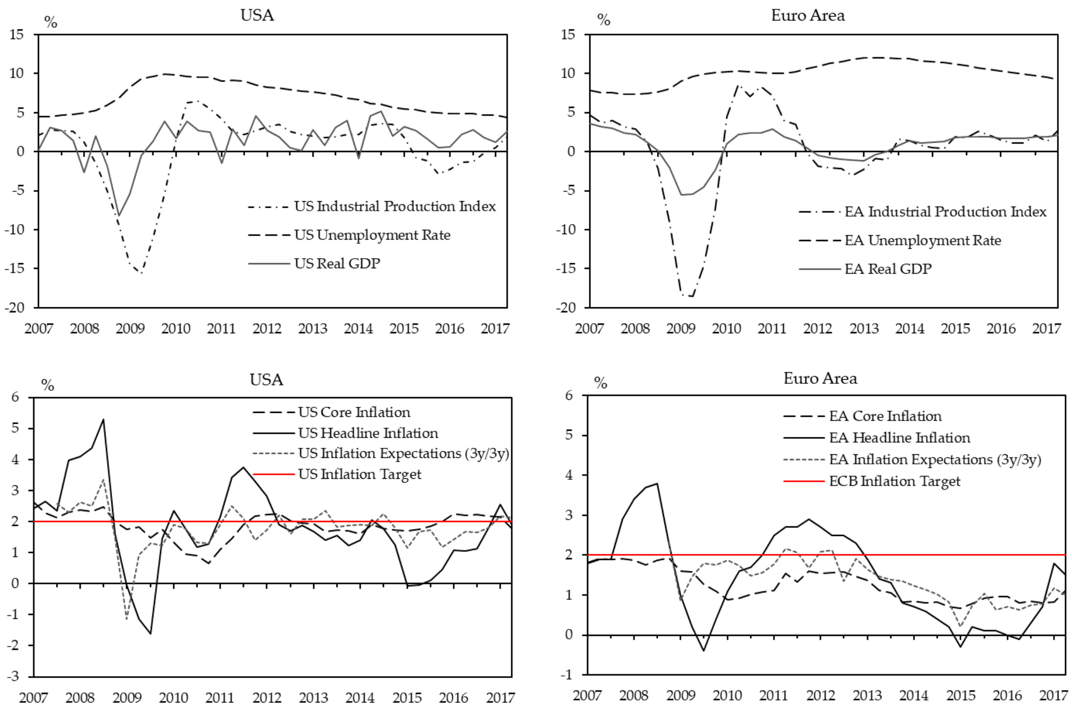

Figure 10.1.: Key macroeconomic indicators ◇ The upper (lower) two panels display real (nominal) variables in the US and the euro area ◇ Inflation expectations are measured as the 3y/3y inflation swap rate (market-based inflation expectations) ◇ *Source:* Eurostat, Fed Fred, ECB, Datastream

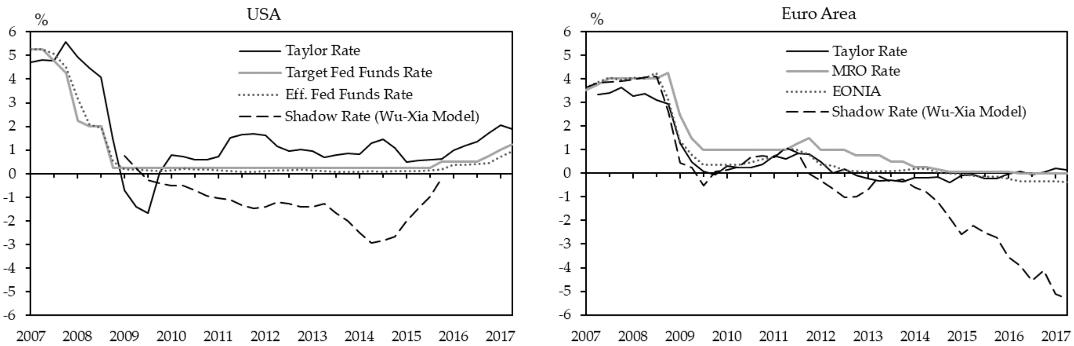

Figure 10.2.: Key policy rates, Taylor rates and shadow policy rates ◇ Using quarterly data, the Taylor rate is estimated according to $i_t = 0.5 i_{t-1} + 0.5[r_t^n + \pi_t^* + 1.5(\pi_t - \pi_t^*) + 0.5(y_t - y_t^*)]$ with $r_t^n = \pi_t^* = 2$ ◇ Due to lack of data, the quarterly output gap for the euro area is interpolated from annual data ◇ *Source:* Wu and Xia (2016), Federal Reserve Bank of Atlanta, Fed Fred, Eurostat, ECB, Datastream

10.2. Principles of Exit Strategies

To mitigate market uncertainty, central banks should communicate the broad principles of exit strategies in a timely manner. This is particularly important since the sequence of unwinding unconventional policies is not conditional on output and inflation alone, but might also be increasingly dependent on financial market conditions. In this context, generally three situations are feasible.

Firstly, the unwinding could occur in an environment of restored financial markets, which, of course, represents the most convenient scenario for an orderly exit. Secondly, inflationary pressures could require more restrictive monetary policy in an environment of impaired financial markets. Finally, to the other extreme, policy makers could be forced to unwind stimulative measures to prevent an overheating of financial markets in light of weak output data and/or subdued inflation dynamics. In any case, prudential policy makers should definitely try to avoid situations where they become trapped with financial stability concerns (*financial dominance*).

Decoupling of Rates and Quantities While the strong dependency on financial market conditions may pose serious constraints on actual policy-making, in principle, the unwinding of liquidity support measures should not present a major challenge for central banks. Due to central banks' ability to pay interest on excess reserves (IOER), balance sheets must *not* necessarily shrink before interest rates rise. In fact, as outlined in section 2.2.4, a main rationale for interest on reserves is that in a situation of large excess reserves, the IOER rate can determine the overnight rate independently of the quantity of reserves.[3]

Problems with Floor Systems In practice, however, running a floor system by paying interest reserves might prove insufficient to adequately control inflation if banks are stuffed with a large stock of excess reserves. One reason is that for the IOER rate to be effective, it has to equal the banks' marginal risk-adjusted lending rates. Since, however, these rates can differ substantially across banks, paying IOER might be more difficult to implement than commonly acknowledged. As a result, a 'one-rate-fits-all' approach could provide a significant subsidy to some banks, while failing to lock up the excess reserves of others. Another concern is that with the IOER rate equal to the average risk-

[3]Initially, as part of the Financial Services Regulatory Relief Act of 2006, the US Congress authorized the Fed to pay interest on required and excess reserves beginning in October 2011. Then, however, as part of the Fed's response to the financial crisis, the right to pay IOER was moved forward to October 2008.

adjusted lending rate, a greater share of the central bank's seignorage revenue will be transferred to banks for the sole reason of holding idle reserves, instead of being remitted to the Treasury (Thornton, 2013).

Apart from this general problem, there exists a peculiar problem with the IOER regime in the United States. By accepting non-bank institutions (mostly GSEs) to hold reserve accounts with the Fed, but not allowing them to earn IOER, policymakers established some kind of legal market segmentation within the US reserve market. In combination with limits to arbitrage, this inconsistency in the policy framework resulted in a persistent 'slippage' of the effective federal funds rate below the IOER rate, which complicates the exit from the zero lower bound by using a floor system (Bech and Klee, 2011; Marquez et al., 2013). Hence, a straightforward solution to fix the interest on reserves floor would be to pay the IOER rate to all institutions that hold reserve accounts with the Fed (Goodfriend, 2015). This, however, would require an act of Congress. Therefore, the Fed has to apply supplementary reserve-drainage operations to better control the effective funds rate upon exit.

Temporary Reserve-Drainage Operations In an attempt to adjust to the institutional deficiency of its IOER regime, the Fed established a fixed-rate reverse repurchase facility (RRP), to which also the GSEs have access.[4] In a reverse repo, the Fed sells a security to an eligible counterparty and simultaneously agrees to buy the security back at a specified maturity date. Thus, RRP transaction does not affect the size of the Fed's balance sheet, because securities sold temporarily under a repo continue to be shown as assets held by the Fed. However, the transaction shifts some of the excess reserves into reverse repos while the trade is outstanding (FOMC, 2015b). In that way, the offering rate on the RRP facility plays a similar role than the IOER rate. Counterparties that can use the RRP facility would not accept an interest rate below the RRP rate, just like depository institutions would be unwilling to accept a rate below the IOER rate.

Currently, the Fed offers an overnight (ON RRP) as well as a term reverse repo facility. The amounts of both operations are limited only by the value of Treasuries held outright on the Fed's balance sheet that are available for these operations. Since some Treasuries are needed for other monetary policy operations, the Fed estimates that about \$2 trillion of Treasuries are available for RRP transactions (FOMC, 2015a).[5] In principle, this

[4]Besides primary dealers, GSEs and a wide set of banks, money market funds are eligible for participation in the RRP operations, too. The whole list of reverse repo counterparties can be found on the homepage of the Federal Reserve Bank of New York.

[5]The Fed's holdings of agency debt and MBS are currently not used in the RRP transactions.

should be enough to temporarily drain a substantial amount of excess reserve from the system. And in fact, the experience during the exit from the zero lower bound suggests that the RRP facility improved the Fed's control over short-term interest rates (Frost et al., 2015).

Reserve Requirements Apart from paying interest on reserves or temporary reserve-drainage operations, another option to prevent an unacceptably large expansion of the money supply would be to substantially increase reserve requirements. While this might represent a feasible strategy for the ECB, the maximum required reserve ratio the Fed can impose on banks has a statutory limit of 14 percent. With currently about $2.4 trillion in excess reserves, this limit is clearly insufficient to counteract a sudden increase in the money supply, because converting those excess reserves into required reserves would require a reserve ratio of near 100 percent (Phelan, 2015).[6] Of course, this statutory limit could be repealed by Congress, which seems, however, highly unlikely in the current political environment.

Asset Sales Finally, central banks can drain excess reserves either by selling securities outright or by stopping the reinvestments of maturing assets on their balance sheets. Prima facie, just allowing bonds to mature seems to be the easiest way to shrink central banks' balance sheets – since it avoids contentious decisions about actual sales – but this would not necessarily be a neutral policy choice (Turner, 2014). One reason is that the weighted average maturity (WAM) of the Fed's portfolio increased from 3.7 years in the pre-crisis era (1970-2007) to above 10 years in 2017 (Bukhari et al., 2013). In comparison, the WAM of the ECB's bond portfolio stands at about 8 years (as of June 2017), implying an even higher increase in maturity relative to the pre-crisis period.[7] Overall, this means that a passive strategy of just stopping the reinvestment of maturing bonds both in the US and the euro area would result in elevated central bank balance sheets way beyond 2025. Yet possibly even more important than maintaining large excess reserves for an extended period of time is the fact that such a passive strategy would make the timing of balance sheet contraction independent of future economic conditions. Given the potentially large impact on financial markets and the macroeconomy, this is clearly an unfavorable outcome for policymakers. Hence, this calls for an active unwinding of

[6] The reserve limit on transaction deposits is established in Section 19 of the Federal Reserve Act.

[7] Prior to the financial crisis, the ECB held negligible amounts of bonds outright. Instead, its regular refinancing operations had a maximum maturity of 3 months, such that the WAM of the ECB's balance sheet, until the onset of the financial crisis, was significantly lower than that of the Fed.

central bank assets where the amount of sales is made conditional on the overall state of the economy (Foerster, 2015).

Sequence of Events Against this background, the Fed noted in its *Policy Normalization Principles and Plans* issued in September 2014 that it intended to increase the federal funds rate primarily by adjusting the interest rate it pays on excess reserves. Secondly, during normalization, the Fed announced that it would use ON RRP facility as a supplementary tool to control the federal funds rate.

Regarding the size of the Fed's balance sheet, the FOMC said it intended to reduce the Fed's securities holdings 'in a gradual and predictable manner primarily by ceasing to reinvest repayments of principal on securities held in the SOMA' (FOMC, 2014). It also noted that it expected phasing out reinvestments after it would begin raising the federal funds rate. Finally, the FOMC stated that 'the Federal Reserve will, in the longer run, hold no more securities than necessary to implement monetary policy efficiently and effectively, and that it will hold primarily Treasury securities, thereby minimizing the effect of Federal Reserve holdings on the allocation of credit across sectors of the economy.' In an addendum to the *Policy Normalization Principles and Plans*, published in June 2017, the FOMC provided more details about its planned approach for the reduction of the Fed's security holdings over time (see FOMC, 2017). In contrast, the ECB has not yet provided detailed information about its intended exit strategy, but it seems likely that it will adopt a more or less similar approach as the Fed. In any event, recent experience – e.g. the bond market reaction to Mario Draghi's speech in Sintra in June 2017, which evoked concerns of a Fed-style 'taper tantrum' in the euro area – underlines the importance of a consistent exit strategy. In this context, careful communication is crucial. In particular, the ECB should use its communication policy and provide sufficient forward guidance about its intended exit steps.

10.3. Potential Exit Costs

10.3.1. Financial Stability Risks

Any assessment of the financial stability risks emanating from the exit of unconventional monetary policies should differentiate between the effects of rising interest rates and the effects of outright asset sales (see IMF, 2013).

Risks from Rising Interest Rates The specific risks associated with increasing interest rates are the following: first, rising interest rates will impose immediate capital losses on fixed-rate assets of banks and other financial intermediaries. These losses have to be weighed against the higher net interest margins of banks, which tend to increase with rising interest rates. While especially weakly capitalized banks will suffer, financial institutions with long-term liabilities, e.g. insurance companies and pension funds, may benefit from rising interest rates. The reason is that the resulting decrease in the net present value of their long-term liabilities may offset the capital losses from lower asset values. Second, rising interest rates may lead to higher credit default rates, especially if the rate hike will be triggered by an increase in inflation instead of improving economic conditions. Third, rising interest rates can lead to sudden and large swings in international capital flows, especially if the timing of tightening differs across central banks.

Risk from Asset Sales Besides interest rate risk, there are also some specific risks associated with asset sales (IMF, 2013). First, even small asset sales could lead to sudden shifts in market sentiment. In turn, this would lead to large spikes in both long- and short-term interest rates, with unintended consequences for the economy. In fact, even the mere possibility of asset sales may increase the uncertainty about interest rate expectations. Under such circumstances, conventional monetary policy faces the risk of losing the contact to market rates. Second, the impact of asset sales on prices is hard to estimate in advance. While sales within well functioning markets should have essentially no effect, dysfunctionalities could suddenly reemerge when assets are sold before the underlying market vulnerabilities have been addressed. Therefore, a widely held view is that central bank communication should focus on an interest rate path instead of specified quantities of asset sales (IMF, 2013). Third, if central banks return to pre-crises corridor systems, the resulting disintermediation of interbank liquidity has to be compensated by a full restoration of private interbank markets. If this is not the case, some banks will face funding constraints.

To address these risks and to safeguard monetary policy from financial dominance, a main task of regulatory authorities is to establish an adequately capitalized banking system. In the meantime, fiscal authorities might be required to recapitalize systemically relevant institutions to prevent bank runs and financial turbulence. To avoid exchange rate misalignments, central bankers should also aim at some international coordination of their exit policies (Bini Smaghi, 2015). Finally, it is of utmost importance to operate a careful communication policy to mitigate the uncertainty surrounding asset sales.

10.3.2. Central Bank Losses

As we have seen earlier, a crucial condition for the effectiveness of unconventional monetary policies is "the central bank's willingness to accept substantial losses contingent on its intervention being ineffective that allows it to move the market to a new trading equilibrium where it does not make losses. Many interventions to infuse liquidity have [thus] an implicit fiscal element to them [...]" (Rajan, 2013, p. 8).

Regardless of this fact, however, higher interest rates and lower bond prices will, ceteris paribus, lead to immediate valuation losses on central bank balance sheets. In normal times, the central bank would avoid to realize such losses by holding the bonds until maturity. In the current situation of large excess reserves and massive bond holdings on central banks' balance sheets, this might be different, however. In particular when inflation overshoots due to large excess reserves, a central bank might be forced to realize losses by selling assets in an environment of rising interest rates. But even if no assets are sold, rising IOER rates will diminish the central bank's net interest income, and this effect increases with the maturities of low-yielding assets on the central bank's balance sheet.

Assuming a policy scenario where short-term rates rise by 400 basis points and long-term rates by 225 basis points (a scenario similar to the Fed's tightening cycle from November 1993 to February 1995), the IMF (2013) estimates that central bank losses would amount to about 3% of domestic GDP in the US, and would exceed 4% of GDP in the UK and Japan.[8]

If the governments had to come up for these losses by recapitalizing their central banks (full fiscal-backing of the central bank balance sheet), they would have to cut down on spending or increase their deficits. However, the full fiscal-backing regime may suffer from a time inconsistency problem. That is, in case of actual losses, it seems questionable whether governments would really use taxpayer money to recapitalize central banks, because, ultimately, central banks cannot go bankrupt. In fact, there exist several examples in economic history where a central bank operated with a negative equity position but was not recapitalized by its government. For instance, in the early 1970s, the Bundesbank recorded a series of substantial losses on its foreign exchange reserves, which ultimately ate up its entire equity (Bundesbank, 1973). In contrast to any private institution, however, the Bundesbank was not insolvent, because it could just print the money to honor its debts (Schlesinger, 2017).

[8] The estimations are based on the asset holdings at the end of 2013.

Losses of the ECB In the event of direct loss incurred by the ECB, Article 33.2 of the ESCB-Statue prescribes that the shortfall should be offset against the general reserve fund and the provisions of the ECB. If those funds prove to be insufficient, then the Governing Council can decide to draw on the monetary income of the NCBs to cover the loss. For such a decision, however, the votes in the Governing Council are weighted according to the national central banks' shares in the subscribed capital of the ECB (cf. Article 10.3 of the ESCB-Statute). Very importantly, while this could principally result in zero net remittances to euro area governments, a further loss absorption through NCBs is not envisioned in the legal framework of the Eurosystem. In particular, there exists no legal obligation for NCBs to redeem an outright loss of the ECB.

Hence, in the (unlikely) event that possible ECB losses are not fully covered by the above procedure, the ECB has to issue deferred assets and disclose a loss carry-forward on its annual accounts, which will need to be redeemed through future profits.

Losses of Euro Area NCBs In principle, the same procedure applies to the NCBs of the Eurosystem. That is, if a NCB suffers a loss, the shortfall has to be offset by the existing loss provision of the respective NCB. Only if the loss provision is depleted shall the NCB issue deferred assets, which need to be run down by future profits. Beyond that, no legal obligation exists that forces the owners of NCBs (i.e. governments) to redeem additional losses at short notice (Bundesbank, 2012). In summary, this suggests that possible central bank losses should not pose a serious constraint on the exit of unconventional monetary policies.[9]

[9] In this context, a striking example is the Bank of Chile, which had negative equity of close to 1% of GDP for almost a decade since 1997, while this did not interfere with an impressive inflation performance (Stella, 2005). For a comparative study of central bank losses in selected countries (Brazil, Chile, Czech Republic, Hungary, Korea, Thailand), see Dalton and Dziobek, 2005.

11. Conclusion and Outlook

In the first part of this thesis, I investigate how monetary policy has been implemented since the outset of the financial crisis. A key result of this part is that central banks' swift and pragmatic decision to act as a *lender of last resort* for temporarily illiquid banks contributed to the stabilization of the financial system and thereby averted greater damage from the economy as a whole.

With the intensification of the crisis, however, these 'passive' lender of last resort operations were increasingly complemented by 'active' unconventional monetary policies involving a manipulation of central banks' balance sheets. As the failure of Lehman Brothers triggered severe turbulences on financial markets and a sharp contraction in economic activity and inflation, central banks in most advanced economies significantly lowered their policy rates and started to massively expand their balance sheets – either through outright monetary transactions (e.g., the Fed's large-scale asset purchases of MBS, agency debt and US Treasuries) or through supplementary refinancing operations against a broad set of collateral (e.g., the ECB's multiple non-standard long-term refinancing operations).

Interestingly, however, these operations were implemented in contradiction to the pre-crisis consensus about the efficacy of such measures. As outlined in chapter 3, the reason is that standard DSGE models like the baseline NK model lack the conditions for central bank asset purchases to have any effect on financial risk premia. Specifically, monetary policy operations that alter the supply of an asset on financial markets have no immediate price effect, except if they change the expectation about the path of future policy rates (*signaling channel*). Nonetheless, most central bankers expected unconventional asset purchases to work primarily through changes in the asset allocation of private portfolios, i.e. through the so-called *portfolio balance effect* (see e.g. Bernanke, 2010).

Thus, one of my key research topics in this thesis is to present a coherent theoretical framework that could capture such a supply-induced portfolio balance effect. Therefore, in chapter 4.2, I delineate a term-structure model in which limits to arbitrage and asset market segmentation produce a state-contingent portfolio balance effect. In particular, in these types of models, shocks to asset quantities constitute a determinant of bond yields *in addition* to current and future policy rates.

Based on the model implications, I then discuss the transmission channels of unconventional monetary policies. In general, the empirical evidence underscores the importance of the portfolio balance effect in the US, the UK, and the euro area. In particular, I find that the ECB's asset purchase program had the biggest impact on distressed periphery countries, which points to a portfolio balance effect that runs primarily through country-specific risk premia (see chapter 6.2). Moreover, I document that unconventional policies in most countries had large international effects.

In part III, I analyze the macroeconomic effects of unconventional monetary policies. In a first step, I assess the impact of various unconventional measures on the banking system (see chapter 7). While the ample provision of central bank money initially triggered a positive liquidity effect, it appears that unconventional measures have been affecting banks primarily through positive wealth effects since the end of 2008.

On the downside, unconventional monetary policies can also have negative consequences for banks: for example, when a flattening term structure weighs on the contribution of maturity transformation on banks' profitability. Then, however, a trade-off could emerge where declining bank profits would require a steeper term structure, while subdued inflation dynamics would call for further monetary easing. To prevent such trade-offs and to produce a more stable financial system, macroprudential policies should ensure that banks are sufficiently capitalized. In the meantime, fiscal authorities might need to recapitalize banks in order to avoid a situation in which monetary policy becomes overburdened by financial stability concerns (*financial dominance*).

In chapter 8, I use a DSGE model to simulate the effect of the portfolio balance channel on output and inflation. Subsequently, I extend this model by a banking sector and the zero lower bound on the short-term policy rate. Based on the model simulations, I show that central bank asset purchases are particularly effective in stabilizing output and inflation when the zero lower bound is binding.

This qualitative evidence for the macroeconomic effectiveness of QE is then compared with the quantitative evidence from the empirical literature. Generally, the existing empirical evidence suggests that the ECB's asset purchase program had a significantly smaller effect on output and inflation than those of the Federal Reserve and the Bank of England. For one thing, this could be due to the fact that the ECB implemented its program at a later date, i.e. when financial market conditions had already normalized, but on the other hand, the lacking economic performance of the euro area appears to be driven to a large extent by the suboptimal structure of the currency union. Since these fundamental deficiencies cannot be resolved by monetary policy, I conclude that the degree of monetary accommodation in the euro area should be slowly reduced.

Finally, I discuss potential exit strategies from unconventional monetary policies. Most importantly, when central banks start to shrink their balance sheets – either by stopping the reinvestment of maturing bonds or by outright asset sales – a key challenge for policymakers is to avoid a disorderly spike in long-term interest rates, since this could pose a serious threat to financial stability. Once again, this underlines the important relation between macroprudential and monetary policies.

Another crucial point is that with the ability to pay interest on reserves, central banks are principally able to withstand inflationary pressures, even in an environment of large excess reserves. Moreover, possible central bank losses should not keep policymakers from exiting unconventional monetary policies at the right time.

Overall, the key lesson of this thesis is that unconventional monetary policies were especially successful in restoring market functioning and impaired interbank intermediation in the early phase of the great financial crisis. Later on, when policy rates reached their effective lower bound, unconventional monetary policies primarily aimed at lowering long-term rates. And although these policies had positive effects on economic activity and inflation, continued policies of this type are associated with substantial risks: e.g., complacency in the necessary reform agenda or increasing financial instability.

Part IV.

Appendix

A. Log-linearization Methods

A.1. Substitution Method

The log-deviation of a variable x_t from its steady state value x is defined as[1]

$$\hat{x}_t \equiv \ln x_t - \ln x \quad \Leftrightarrow \quad \ln x_t = \ln x + \hat{x}_t. \qquad \langle A.1 \rangle$$

Employing a Taylor approximation to the right hand side of equation ⟨A.1⟩, it can be written as

$$\ln\left(\frac{x_t}{x}\right) = \ln\left(1 + \frac{x_t - x}{x}\right) \approx \ln 1 + \frac{1}{x}(x_t - x) = \frac{x_t - x}{x}. \qquad \langle A.2 \rangle$$

Putting this together yields the basic results,

$$\hat{x}_t \approx \frac{x_t - x}{x} = \frac{x_t}{x} - 1 \qquad \langle A.3 \rangle$$

$$\frac{x_t}{x} \approx 1 + \hat{x}_t \qquad \langle A.4 \rangle$$

$$x_t \approx x(1 + \hat{x}_t) \qquad \langle A.5 \rangle$$

A more general result for ⟨A.1⟩ is obtained by taking exponents,

$$x_t = e^{\ln x + \hat{x}_t} = e^{\ln x} e^{\hat{x}_t} = x e^{\hat{x}_t}$$

$$\Leftrightarrow \frac{x_t}{x} = e^{\hat{x}_t} \qquad \langle A.6 \rangle$$

Again, approximating the right hand side of equation ⟨A.6⟩ by a first-order Taylor polynomial at the point $\hat{x}_t = 0$, yields

$$e^{\hat{x}_t} \approx e^0 + e^0(\hat{x}_t - 0) = 1 + \hat{x}_t. \qquad \langle A.7 \rangle$$

[1]This section draws in large parts on Zietz (2006) and McCandless (2008).

Taking into account ⟨A.6⟩, this can be generalized to

$$x_t^\alpha = \left(xe^{\hat{x}_t}\right)^\alpha = x^\alpha e^{\alpha \hat{x}_t} \approx x^\alpha \left(1 + \alpha \hat{x}_t\right). \tag{A.8}$$

A.2. Taylor Series Approximation Method

The direct substitution method can be rather cumbersome for more complex or even multivariate functions. In these cases, it is often more convenient to firstly use a Taylor series approximation before applying the definitions for log-deviations from the steady state. Consider a multivariate function with two endogenous variables like

$$x_t = g(x_t,\ y_t), \tag{A.9}$$

which can be approximated by a first-order Taylor expansion around the steady state values $x_t = x$ and $y_t = y$,

$$x_t \approx g(x,\ y) + g'_x(x,\ y)(x_t - x) + g'_y(x,\ y)(y_t - y). \tag{A.10}$$

With the steady state value $x = g(x,\ y)$ the above equation can be transformed to

$$\frac{x_t}{x} \approx 1 + g'_x(x,\ y)\frac{(x_t - x)}{x} + g'_y(x,\ y)\frac{y}{x}\frac{(y_t - y)}{y}. \tag{A.11}$$

Using the equations ⟨A.3⟩ and ⟨A.4⟩ for log-deviations from the steady state, this can be rearranged to the the following sequence of equations,

$$\begin{aligned} 1 + \hat{x}_t &\approx 1 + g'_x(x,\ y)\hat{x}_t + g'_y(x,\ y)\frac{y}{x}\hat{y}_t \\ \Leftrightarrow \hat{x}_t &\approx g'_x(x,\ y)\hat{x}_t + g'_y(x,\ y)\frac{y}{x}\hat{y}_t \\ \Leftrightarrow x\hat{x}_t &\approx g'_x(x,\ y)x\hat{x}_t + g'_y(x,\ y)y\hat{y}_t \end{aligned} \tag{A.12}$$

For most equations in complex DSGE-models, the best way to perform the log-linearization process is to apply equation ⟨A.12⟩ directly.

B. Selected Proofs and Derivations

B.1. Corridor Model

To calculate the FOCs of the corridor model of section 2.2, notice that

$$\frac{\partial}{\partial I_j}\int_{T_j\to-\infty}^{RH_j+I_j+RP_j}(RH_j+I_j+RP_j-T_j)f(T_j)\mathsf{d}T_j=\int_{T_j\to-\infty}^{RH_j+I_j+RP_j}f(T_j)\mathsf{d}T_j$$
$$+\left((RH_j+I_j+P_j)-(RH_j+I_j+RP_j)\right)f(RH_j+I_j+RP_j)$$
$$=F(RH_j+I_j+RP_j),\quad \langle\text{B.1}\rangle$$

while

$$\frac{\partial}{\partial I_j}\int_{T_j=RH_j+I_j+RP_j}^{T_j\to\infty}(RH_j+I_j+RP_j-T_j)f(T_j)\mathsf{d}T_j$$
$$=1-F(RH_j+I_j+RP_j),\quad \langle\text{B.2}\rangle$$

where $F(T_j)$ denotes the distribution function of $f(T_j)$. Using this information, the first-order condition reduces to

$$-i+i_dF(RH_j+I_j+RP_j)+i_b(1-F(RH_j+I_j+RP_j))=0.\quad \langle\text{B.3}\rangle$$

This can be rearranged to

$$(i_b-i)(1-F(RH_j+I_j+RP_j))=(i-i_d)F(RH_j+I_j+RP_j),\quad \langle\text{B.4}\rangle$$

which corresponds to equation ⟨2.10⟩ in the main text.

B.2. Baseline NKM

Optimal Consumption Profile Household chooses consumption bundle that maximizes total consumption

$$\max_{C_{it}} \left(\int_0^1 C_{it}^{\frac{\epsilon-1}{\epsilon}} \mathsf{d}i \right)^{\frac{\epsilon}{\epsilon-1}} \tag{B.5}$$

subject to the expenditure constraint

$$\bar{Z}_t \geq \int_0^1 P_{it} C_{it} \mathsf{d}i. \tag{B.6}$$

The Lagrangian to this problem reads

$$\mathcal{L} = \left(\int_0^1 C_{it}^{\frac{\epsilon-1}{\epsilon}} \mathsf{d}i \right)^{\frac{\epsilon}{\epsilon-1}} - \lambda_t \left(\int_0^1 P_{it} C_{it} \mathsf{d}i - \bar{Z}_t \right) \tag{B.7}$$

with the FOCs:

$$\frac{\partial \mathcal{L}}{\partial C_{it}} = C_t^{\frac{1}{\epsilon}} C_{it}^{-\frac{1}{\epsilon}} = \lambda_t P_{it} \tag{B.8}$$

$$\frac{\partial \mathcal{L}}{\partial C_{jt}} = C_t^{\frac{1}{\epsilon}} C_{jt}^{-\frac{1}{\epsilon}} = \lambda_t P_{jt}. \tag{B.9}$$

Dividing the two FOCs yields consumption demand for good i and j

$$C_{it} = C_{jt} \left(\frac{P_{it}}{P_{jt}} \right)^{-\epsilon} \qquad \forall i, j. \tag{B.10}$$

The aggregate price index is given as

$$P_t \equiv \left(\int_0^1 P_{it}^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}}. \tag{B.11}$$

Inserting consumption demand ⟨B.10⟩ and price index ⟨B.11⟩ into expenditure constraint ⟨B.6⟩ and solve for C_{jt}

$$\bar{Z}_t = \int_0^1 P_{it} C_{it} \mathsf{d}i = \int_0^1 P_{it} C_{jt} \left(\frac{P_{it}}{P_{jt}} \right)^{-\epsilon} \mathsf{d}i = \int_0^1 P_{it}^{1-\epsilon} \mathsf{d}i P_{jt}^{\epsilon} C_{jt}$$

$$\Leftrightarrow \bar{Z}_t = \left[\underbrace{\left(\int_0^1 P_{it}^{1-\epsilon} \mathsf{d}i \right)^{\frac{1}{1-\epsilon}}}_{P_t} \right]^{1-\epsilon} P_{jt}^{\epsilon} C_{jt} = P_t^{1-\epsilon} P_{jt}^{\epsilon} C_{jt} = P_t \left(\frac{P_{jt}}{P_t} \right)^{\epsilon} C_{jt} \quad \forall i, j$$

$$\Leftrightarrow C_{jt} = \left(\frac{P_{jt}}{P_t} \right)^{-\epsilon} \frac{\bar{Z}_t}{P_t} \quad \forall i, j \tag{B.12}$$

Then, insert ⟨B.12⟩ into Dixit-Stiglitz Aggregator ⟨3.4⟩ to get

$$C_t = \left(\int_0^1 C_{it}^{\frac{\epsilon-1}{\epsilon}} \mathsf{d}i \right)^{\frac{\epsilon}{\epsilon-1}} = \left(\int_0^1 \left[\left(\frac{P_{it}}{P_t} \right)^{-\epsilon} \frac{\bar{Z}_t}{P_t} \right]^{\frac{\epsilon-1}{\epsilon}} \mathsf{d}i \right)^{\frac{\epsilon}{\epsilon-1}}$$

$$= \left(\int_0^1 \left[P_{it}^{-\epsilon} \bar{Z}_t P_t^{\epsilon-1} \right]^{\frac{\epsilon-1}{\epsilon}} \mathsf{d}i \right)^{\frac{\epsilon}{\epsilon-1}} = \bar{Z}_t P_t^{\epsilon-1} \left(\int_0^1 P_{it}^{1-\epsilon} \mathsf{d}i \right)^{\frac{\epsilon}{\epsilon-1}}$$

$$= \bar{Z}_t P_t^{\epsilon-1} \left[\left(\int_0^1 P_{it}^{1-\epsilon} \mathsf{d}i \right)^{\frac{1}{1-\epsilon}} \right]^{-\epsilon} = \bar{Z}_t P_t^{\epsilon-1-\epsilon}$$

$$\Leftrightarrow \bar{Z}_t = P_t C_t. \tag{B.13}$$

Finally, insert ⟨B.13⟩ into ⟨B.12⟩ to get

$$C_{jt} = \left(\frac{P_{jt}}{P_t} \right)^{-\epsilon} C_t \quad \forall i, j \tag{B.14}$$

which corresponds to equation ⟨3.5⟩ in the main text.

Optimal Allocation of Consumption and Labor For $T_t = 0$, the household faces the optimization problem

$$\mathcal{L} = \mathrm{E}_t \sum_{t=0}^{\infty} \left\{ \beta^t u(C_t, N_t) - \lambda_t (P_t C_t + Q_t B_t - B_{t-1} - W_t N_t) \right\} \tag{B.15}$$

with FOCs

$$\frac{\partial \mathcal{L}}{\partial C_t} = C_t^{-\sigma} - \lambda_t P_t = 0 \tag{B.16}$$

$$\frac{\partial \mathcal{L}}{\partial N_t} = N_t^{\varphi} - \lambda_t W_t = 0 \tag{B.17}$$

$$\frac{\partial \mathcal{L}}{\partial B_t} = -\lambda_t Q_t + \beta \lambda_{t+1} = 0 \tag{B.18}$$

Combining ⟨B.16⟩ and ⟨B.18⟩ while exploiting that $\lambda_{t+1} = \frac{C_{t+1}^{-\sigma}}{P_{t+1}}$ (which follows from forward iteration of ⟨B.16⟩), gives

$$\frac{C_t^{-\sigma}}{P_t} = \frac{\beta\lambda_{t+1}}{Q_t} = \frac{\beta C_{t+1}^{-\sigma}}{Q_t P_{t+1}}$$

$$\Leftrightarrow C_t^{-\sigma} = \frac{\beta C_{t+1}^{-\sigma}}{Q_t}\frac{P_t}{P_{t+1}} = \beta C_{t+1}^{-\sigma}(1+i_t)\pi_{t+1}^{-1} \qquad \langle B.19\rangle$$

With $\ln\beta = \ln\frac{1}{1+\rho} = \ln 1 - \ln(1+\rho) \approx -\rho$ this can be log-linearized to

$$-\sigma c_t = \ln 1 - \ln(1+\rho) + \ln(1+i_t) - \sigma c_{t+1} - \pi_{t+1} \approx -\rho + i_t - \sigma c_{t+1} - \pi_{t+1}$$

$$\Leftrightarrow c_t = c_{t+1} - \frac{1}{\sigma}[i_t - \pi_{t+1} - \rho] \qquad \langle B.20\rangle$$

where the last line corresponds to the Euler equation ⟨3.13⟩ of the main text.

Firms' Optimal Price Setting The firms' optimization problem reads

$$\max_{P_t^*} \mathcal{L} = \sum_{k=0}^{\infty}\theta^k \mathrm{E}_t\Bigg[\underbrace{\beta^k\left(\frac{C_{t+k}}{C_t}\right)^{-\sigma}\left(\frac{P_t}{P_{t+k}}\right)}_{DiscountFactor}\underbrace{\left(P_t^*\left(\frac{P_t^*}{P_{t+k}}\right)^{-\epsilon}C_{t+k}\right.}_{Revenues}$$
$$\left.-\underbrace{\Psi_{t+k}\Big(\left(\frac{P_t^*}{P_{t+k}}\right)^{-\epsilon}C_{t+k}\Big)\Big)}_{Costs}\Bigg]. \qquad \langle B.21\rangle$$

Taking the FOC delivers

$$\frac{\partial\mathcal{L}}{\partial P_t^*} = \sum_{k=0}^{\infty}\theta^k \mathrm{E}_t\Bigg[\beta^k\left(\frac{C_{t+k}}{C_t}\right)^{-\sigma}\left(\frac{P_t}{P_{t+k}}\right)\Bigg((1-\epsilon)\left(\frac{P_t^*}{P_{t+k}}\right)^{-\epsilon}C_{t+k}$$
$$+\Psi'_{t+k}\epsilon\left(\frac{P_t^*}{P_{t+k}}\right)^{-\epsilon-1}\frac{C_{t+k}}{P_{t+k}}\Bigg)\Bigg] = 0 \qquad \langle B.22\rangle$$

Substituting back

$$Y_{t+k|t} = \left(\frac{P_t^*}{P_{t+k}}\right)^{-\epsilon}C_{t+k} \qquad \langle B.23\rangle$$

and the stochastic discount factor

$$Q_{t+k} \equiv \beta^k \left(\frac{C_{t+k}}{C_t}\right)^{-\sigma} \left(\frac{P_t}{P_{t+k}}\right) \tag{B.24}$$

yields

$$\sum_{k=0}^{\infty} \theta^k \mathrm{E}_t \left[Q_{t+k} \left((1-\epsilon) Y_{t+k|t} + \Psi'_{t+k} \epsilon Y_{t+k|t} \left(\frac{P_t^*}{P_{t+k}} \right)^{-1} \frac{1}{P_{t+k}} \right) \right] = 0$$

$$\Leftrightarrow \sum_{k=0}^{\infty} \theta^k \mathrm{E}_t \left[Q_{t+k} Y_{t+k|t} \left((1-\epsilon) + \Psi'_{t+k} \frac{1}{P_t^*} \right) \right] = 0 \tag{B.25}$$

which can be simplified by multiplying both sides with P_t^* and $\frac{1}{1-\epsilon}$ to end up with

$$\sum_{k=0}^{\infty} \theta^k \mathrm{E}_t \left[Q_{t+k} Y_{t+k|t} \left(P_t^* - \frac{\epsilon}{\epsilon - 1} \Psi'_{t+k} \right) \right] = 0. \tag{B.26}$$

This corresponds to equation ⟨3.20⟩ of the main text. Solving this expression for P_t^* and re-substituting ⟨B.23⟩ and ⟨B.24⟩ finally yields

$$P_t^* = \frac{\epsilon}{\epsilon - 1} \frac{\mathrm{E}_t \sum_{k=0}^{\infty} \theta^k \beta^k C_{t+k}^{1-\sigma} P_{t+k}^{\epsilon} MC_{t+k|t}^r}{\mathrm{E}_t \sum_{k=0}^{\infty} \theta^k \beta^k C_{t+k}^{1-\sigma} P_{t+k}^{\epsilon-1}} \tag{B.27}$$

Equilibrium Analysis From log-linearization of the production function ⟨3.14⟩ it follows that

$$y_t = z_t + (1-\alpha) n_t \Leftrightarrow n_t = \frac{y_t - z_t}{1-\alpha} \tag{B.28}$$

Further, average marginal costs are given by

$$mc_t^r = (w_t - p_t) - mpn_t = (w_t - p_t) - (z_t - \alpha n_t) - \ln(1-\alpha) \tag{B.29}$$

Inserting ⟨B.28⟩ for n_t gives

$$mc_t^r = (w_t - p_t) - \frac{z_t - \alpha y_t}{1-\alpha} - \ln(1-\alpha). \tag{B.30}$$

Likewise, the marginal cost in $t+k$ for a firm i that set its optimal price in t is given by

$$mc_{t+k|t}^r = (w_{t+k} - p_{t+k}) - \frac{z_{t+k} - \alpha y_{t+k|t}}{1-\alpha} - \ln(1-\alpha). \tag{B.31}$$

From ⟨B.14⟩ and the goods market clearing condition $Y_t = C_t$, it follows that

$$Y_{t+k|t} = \left(\frac{P_{t+k|t}}{P_{t+k}}\right)^{-\epsilon} Y_{t+k} \qquad \langle B.32\rangle$$

which can be log-linearized to

$$y_{t+k|t} = -\epsilon(p_{t+k|t} - p_{t+k}) + y_{t+k}. \qquad \langle B.33\rangle$$

Thus, subtracting ⟨B.30⟩ from ⟨B.31⟩ and using the above expression gives

$$\begin{aligned} mc^r_{t+k|t} - mc^r_{t+k} &= \left[(w_{t+k} - p_{t+k}) - \frac{z_{t+k} - \alpha y_{t+k|t}}{1-\alpha} - \ln(1-\alpha)\right] \\ &- \left[(w_{t+k} - p_{t+k}) - \frac{z_{t+k} - \alpha y_{t+k}}{1-\alpha} - \ln(1-\alpha)\right] \\ &= \frac{\alpha}{1-\alpha}(y_{t+k|t} - y_{t+k}) \\ &= \frac{\alpha}{1-\alpha}\left[-\epsilon(p_{t+k|t} - p_{t+k}) + y_{t+k} + \epsilon(p_{t+k} - p_{t+k}) - y_{t+k}\right] \\ &= -\frac{\epsilon\alpha}{1-\alpha}(p^*_t - p_{t+k}) \qquad \langle B.34\rangle \end{aligned}$$

where in the last line it was used that $p_{t+k|t} = p^*_t$. Finally, this can be rearranged to

$$mc^r_{t+k|t} = mc^r_{t+k} - \frac{\alpha\epsilon}{1-\alpha}(p^*_t - p_{t+k}) \qquad \langle B.35\rangle$$

which equals ⟨3.30⟩ of the main text. Using this expression in the optimal price setting equation ⟨3.26⟩, which is re-written here as

$$p^*_t - p_{t-1} = (1-\theta\beta)\mathrm{E}_t \sum_{k=0}^{\infty} \theta^k \beta^k [mc^r_{t+k|t} - mc^r + p_{t+k} - p_{t-1}] \qquad \langle B.36\rangle$$

yields

$$p^*_t - p_{t-1} = (1-\theta\beta)\mathrm{E}_t \sum_{k=0}^{\infty} \theta^k \beta^k [mc^r_{t+k} - \frac{\alpha\epsilon}{1-\alpha}(p^*_t - p_{t+k}) - mc^r + p_{t+k} - p_{t-1}]$$

which can be simplified to

$$p^*_t - \frac{1-\alpha}{1-\alpha+\alpha\epsilon} p_{t-1} = -\frac{1-\alpha}{1-\alpha+\alpha\epsilon} p_{t-1}$$

$$+ (1-\theta\beta)\mathrm{E}_t \sum_{k=0}^{\infty} \theta^k \beta^k \left(\frac{1-\alpha}{1-\alpha+\alpha\epsilon} \widehat{mc}^r_{t+k} + p_{t+k} \right). \quad \langle B.37 \rangle$$

Defining $\Theta = \frac{1-\alpha}{1-\alpha+\alpha\epsilon}$ and subtracting $(1-\Theta)p_{t-1}$ from both sides of the above equation results in

$$p^*_t - p_{t-1} = (1-\theta\beta)\Theta\mathrm{E}_t \sum_{k=0}^{\infty} \theta^k \beta^k \widehat{mc}^r_{t+k} + \sum_{k=0}^{\infty} \theta^k \beta^k \pi_{t+k}. \quad \langle B.38 \rangle$$

Taking out $k = 0$ from the summation operator yields the difference equation

$$p^*_t - p_{t-1} = \theta\beta \left[(1-\theta\beta)\Theta\mathrm{E}_t \sum_{k=0}^{\infty} \theta^k \beta^k \widehat{mc}^r_{t+k+1} + \sum_{k=0}^{\infty} \theta^k \beta^k \pi_{t+k+1} \right]$$

$$+ (1-\theta\beta)\Theta\widehat{mc}^r_t + \pi_t = \theta\beta\mathrm{E}_t(p^*_{t+1} - p_t) + (1-\theta\beta)\Theta\widehat{mc}^r_t + \pi_t \quad \langle B.39 \rangle$$

where the term in brackets was substituted with ⟨B.38⟩ iterated one period forward. Next, inserting the equation for aggregate inflation $\pi_t = (1-\theta)(p^*_t - p_{t-1})$ and solving for $p^*_t - p_{t-1}$ finally yields

$$p^*_t - p_{t-1} = \theta\beta\mathrm{E}_t(p^*_{t+1} - p_t) + (1-\theta\beta)\Theta\widehat{mc}^r_t + (1-\theta)(p^*_t - p_{t-1})$$

$$\Leftrightarrow \pi_t = \beta\mathrm{E}_t\{\pi_{t+1}\} + \bar{\lambda}\widehat{mc}^r_t \quad \langle B.40 \rangle$$

where $\bar{\lambda} = \frac{(1-\theta)(1-\theta\beta)}{\theta}\Theta = \frac{(1-\theta)(1-\theta\beta)}{\theta}\frac{1-\alpha}{1-\alpha+\alpha\epsilon}$ has been defined to ease the notation. This is the expression for the NKPC as a function of marginal costs corresponding to equation ⟨3.31⟩ of the main text.

B.3. Preferred-Habitat Model

The following calculations present the optimization problem of the risk-averse arbitrageurs in a discretized version of the Vayanos and Vila (2009) framework of section 4.2, drawing in some parts on Altavilla et al. (2015), Hayashi (2016), and Hamilton and Wu (2012).

First, notice that $P_t^{(n)}$ is the price of a zero-coupon bond with maturity n in period t. Thus, by convention, we set $P_t^{(1)} = 1$. The continuously compounded yield to maturity $y_t^{(n)}$ is therefore

$$y_t^{(n)} = -\frac{\log P_t^{(n)}}{n} = -\frac{p_t^{(n)}}{n}, \tag{B.41}$$

where $p_t^{(n)} = \log P_t^{(n)}$. Combining ⟨4.3⟩ with ⟨4.4⟩ yields

$$p_{t+1}^{(n-1)} - p_t^{(n)} = \bar{a}_{n-1} + \bar{b}'_{n-1}\left(c + \Phi f_t\right) - \bar{a}_n - \bar{b}'_n f_t + \bar{b}_{n-1}\epsilon_{t+1} \tag{B.42}$$

The expectation of this function conditional on time t, is

$$E_t\left[p_{t+1}^{(n-1)} - p_t^{(n)}\right] = \bar{a}_{n-1} + \bar{b}'_{n-1}\left(c + \Phi f_t\right) - \bar{a}_n - \bar{b}'_n f_t \tag{B.43}$$

and its variance is governed by the error term $\epsilon_t \sim N(0, \Omega)$, which is given by

$$Var_t\left(p_{t+1}^{(n-1)} - p_t^{(n)}\right) = \bar{b}'_{n-1}\Omega\bar{b}_{n-1}. \tag{B.44}$$

Thus, the per-period bond price difference conditional on time t follows a normal distribution with mean and variance according to ⟨B.43⟩ respectively ⟨B.44⟩. This information can be used to write

$$\begin{aligned}
E_t\left[\frac{P_{t+1}^{(n-1)} - P_t^{(n)}}{P_t^{(n)}}\right] &= E_t\left[\exp\left(p_{t+1}^{(n-1)} - p_t^{(n)}\right)\right] - 1 \\
&= \exp\left[E_t\left(p_{t+1}^{(n-1)} - p_t^{(n)}\right) + \frac{1}{2}Var_t\left(p_{t+1}^{(n-1)} - p_t^{(n)}\right)\right] - 1 \\
&\approx E_t\left(p_{t+1}^{(n-1)} - p_t^{(n)}\right) + \frac{1}{2}Var_t\left(p_{t+1}^{(n-1)} - p_t^{(n)}\right)
\end{aligned} \tag{B.45}$$

In the second row the formula for a normally distributed random variable X was used, i.e. $E_t[\exp(X)] = \exp[E(X) + 1/2Var(X)]$, which is a valid transformation, since $X = p_{t+1}^{(n-1)} - p_t^{(n)}$ is a normally distributed variable (as shown above). In the third row, the approximation $\exp(x) \approx 1 + x$ for $x = E_t\left(p_{t+1}^{(n-1)} - p_t^{(n)}\right) + \frac{1}{2}Var_t\left(p_{t+1}^{(n-1)} - p_t^{(n)}\right)$ was applied.[1] Substituting ⟨B.43⟩ and ⟨B.44⟩ into ⟨B.45⟩ yields the risky bond return, $R_{t+1}^{(n)}$, as

$$R_{t+1}^{(n)} = \bar{a}_{n-1} + \bar{b}_{n-1}'(c + \Phi f_t) - \bar{a}_n - \bar{b}_n' f_t + \frac{1}{2}\bar{b}_{n-1}'\Omega\bar{b}_{n-1}, \quad \langle B.46\rangle$$

while the risk-free rate, r_t, is defined to be the same as the yield on the one-period bond, $y_t^{(1)}$. Since this return is known with certainty at time t, its variance is zero, such that

$$r_t = y_t^{(1)} = -\bar{a}_1 - \bar{b}_1' f_t. \quad \langle B.47\rangle$$

With $z_t^{(n)}$ being the portfolio share of n-period bonds, the portfolio return of arbitrageurs is

$$\begin{aligned} R_{pf,t+1} &\equiv \sum_{n=1}^{N} R_{t+1}^{(n)} z_t^{(n)} = \sum_{n=1}^{N} \frac{P_{t+1}^{(n-1)} - P_t^{(n)}}{P_t^{(n)}} z_t^{(n)} \\ &= \sum_{n=1}^{N} \left[\exp\left(p_{t+1}^{(n-1)} - p_t^{(n)}\right) - 1\right] z_t^{(n)} \end{aligned} \quad \langle B.48\rangle$$

resulting in a maximization problem of

$$\max_{z_t^{(n)}} \left[E_t\left(R_{pf,t+1}\right) - \frac{\sigma}{2} Var_t\left(R_{pf,t+1}\right)\right] \quad \langle B.49\rangle$$

subject to

$$\sum_{n=1}^{N} z_t^{(n)} = 1. \quad \langle B.50\rangle$$

With

$$\begin{aligned} E_t(R_{pf,t+1}) &= \sum_{n=1}^{N} z_t^{(n)} \left[\bar{a}_{n-1} + \bar{b}_{n-1}'\left(c + \Phi f_t\right) + \frac{1}{2}\bar{b}_{n-1}'\Omega\bar{b}_{n-1} - \bar{a}_n - \bar{b}_n' f_t\right] \\ &= \sum_{n=1}^{N} z_t^{(n)} \left[\bar{a}_{n-1} + \bar{b}_{n-1}'c + \left(\bar{b}_{n-1}'\Phi - \bar{b}_n'\right) f_t - \bar{a}_n + \frac{1}{2}\bar{b}_{n-1}'\Omega\bar{b}_{n-1}\right] \end{aligned} \quad \langle B.51\rangle$$

[1] Note that $\exp(x) \approx 1 + x$ is a valid approximation only for $x \approx 0$. Hence, for large fluctuations of per-period bond price differentials, this transformation delivers bad results.

and

$$Var_t(R_{pf,t+1}) = \sum_{n=1}^{N} z_t^{(n)} \left[\bar{b}'_{n-1} \Omega \sum_{n=1}^{N} z_t^{(n)} \bar{b}_{n-1} \right]. \quad \langle B.52 \rangle$$

Equations ⟨B.49⟩, ⟨B.50⟩, ⟨B.51⟩, and ⟨B.52⟩ can be combined to yield the Lagrangian

$$\mathcal{L} = \sum_{n=1}^{N} z_t^{(n)} \left[\bar{a}_{n-1} + \bar{b}'_{n-1} c + \left(\bar{b}'_{n-1} \Phi - \bar{b}'_n \right) f_t - \bar{a}_n + \frac{1}{2} \bar{b}'_{n-1} \Omega \bar{b}_{n-1} \right] - \frac{\sigma}{2} \left[\sum_{n=1}^{N} z_t^{(n)} \left(\bar{b}'_{n-1} \Omega \sum_{n=1}^{N} z_t^{(n)} \bar{b}_{n-1} \right) \right] - \lambda_t \sum_{n=1}^{N} z_t^{(n)} \quad \langle B.53 \rangle$$

with the FOCs

$$\frac{\partial \mathcal{L}}{\partial z_t^{(n)}} = \left[\bar{a}_{n-1} + \bar{b}'_{n-1} c + \left(\bar{b}'_{n-1} \Phi - \bar{b}'_n \right) f_t - \bar{a}_n + \frac{1}{2} \bar{b}'_{n-1} \Omega \bar{b}_{n-1} \right] - \frac{\sigma}{2} \left(\bar{b}'_{n-1} \Omega \sum_{n=1}^{N} z_t^{(n)} \bar{b}_{n-1} \right) - \frac{\sigma}{2} \sum_{n=1}^{N} z_t^{(n)} \left(\bar{b}'_{n-1} \Omega \bar{b}_{t-1} \right) - \lambda_t = 0 \quad \langle B.54 \rangle$$

and

$$\frac{\partial \mathcal{L}}{\partial z_t^{(1)}} = -\bar{a}_1 - \bar{b}'_1 f_t - \lambda_t = 0. \quad \langle B.55 \rangle$$

Combining the FOCs gives

$$\left[\bar{a}_{n-1} + \bar{b}'_{n-1}(c + \Phi f_t) - \bar{a}_n - \bar{b}'_n f_t + \frac{1}{2} \bar{b}'_{n-1} \Omega \bar{b}_{n-1} \right] + \left[\bar{a}_1 + \bar{b}'_1 f_t \right] = \sigma \sum_{n=1}^{N} z_t^{(n)} \left(\bar{b}'_{n-1} \Omega \bar{b}_{t-1} \right) = \bar{b}'_{n-1} \Omega \sigma \sum_{n=1}^{N} z_t^{(n)} \bar{b}_{n-1}. \quad \langle B.56 \rangle$$

Using equations ⟨B.46⟩ and ⟨B.47⟩ on the left hand side of ⟨B.56⟩, and the market price of risk,

$$\varphi_t = \sigma \sum_{n=1}^{N} z_t^{(n)} \bar{b}_{n-1}, \quad \langle B.57 \rangle$$

on the right hand side, gives the risk premium as

$$R_{t+1}^{(n)} - r_t = \bar{b}'_{n-1} \Omega \varphi_t. \quad \langle B.58 \rangle$$

This expression corresponds to equation ⟨4.6⟩ of the main text. As stated above, it defines the risk premium on long-term bonds as the product of the quantity of risk, $\bar{b}'_{n-1}\Omega$, times the market price of risk, φ_t.

B.4. Reserve-Induced Portfolio Balance Model

This section illustrates how to derive equation ⟨5.36⟩ in the main text. The calculations draw on the two asset model as presented in Christensen and Krogstrup (2016a, pp. 19-23).

The Central Bank Including short-term bonds (B_S) changes the central bank's balance sheet to

$$P_S B_S^{CB} + P_L B_L^{CB} = E^{CB} + R \tag{B.59}$$

where it is assumed that B_S^{CB} is the central bank's policy tool.

Non-Banks Accordingly, the balance sheet of the non-bank sector is given by

$$P_S B_S^{NB} + P_L B_L^{NB} + D^{NB} = E^{NB}. \tag{B.60}$$

Since the non-bank sector as a whole is granted with deposits whenever selling bonds, it holds that

$$P_S \mathsf{d} B_S^{CB} + P_L \mathsf{d} B_L^{CB} = -\mathsf{d} D^{NB}, \tag{B.61}$$

thus, changes in non-banks' equity derive from price changes in its bond holdings, i.e.

$$\mathsf{d} E^{NB} = \mathsf{d} P_S B_S^{NB} + \mathsf{d} P_L B_L^{NB}. \tag{B.62}$$

The non-banks' demand for short- and long-term bonds is a function of bond prices and non-banks' equity

$$B_S^{NB} = f_S^{NB}(P_S, P_L, E^{NB}) \tag{B.63}$$

$$B_L^{NB} = f_L^{NB}(P_S, P_L, E^{NB}) \tag{B.64}$$

with

$$\frac{\partial f_S^{NB}(P_S, P_L, E^{NB})}{\partial P_S} < 0 \quad \text{and} \quad \frac{\partial f_L^{NB}(P_S, P_L, E^{NB})}{\partial P_L} < 0 \tag{B.65}$$

and

$$\frac{\partial f_S^{NB}(P_S, P_L, E^{NB})}{\partial P_L} > 0 \quad \text{and} \quad \frac{\partial f_L^{NB}(P_S, P_L, E^{NB})}{\partial P_S} > 0 \tag{B.66}$$

where the negative cross-price elasticities express the imperfect substitutability between short- and long-term bonds. As in the main text, it is assumed that non-banks do not react to changes in its equity value by changing their bond demand, such that

$$\frac{\partial f_S^{NB}(P_S, P_L, E^{NB})}{\partial E^{NB}} = \frac{\partial f_L^{NB}(P_S, P_L, E^{NB})}{\partial E^{NB}} = 0. \qquad \langle \text{B.67} \rangle$$

Using this information in equations ⟨B.63⟩ and ⟨B.64⟩ yields

$$\mathsf{d}B_S^{NB} = \frac{\partial f_S^{NB}(P_S, P_L, E^{NB})}{\partial P_S}\mathsf{d}P_S + \frac{\partial f_S^{NB}(P_S, P_L, E^{NB})}{\partial P_L}\mathsf{d}P_L, \qquad \langle \text{B.68} \rangle$$

$$\mathsf{d}B_L^{NB} = \frac{\partial f_L^{NB}(P_S, P_L, E^{NB})}{\partial P_S}\mathsf{d}P_S + \frac{\partial f_L^{NB}(P_S, P_L, E^{NB})}{\partial P_L}\mathsf{d}P_L. \qquad \langle \text{B.69} \rangle$$

Finally, substituting ⟨B.68⟩ and ⟨B.69⟩ into ⟨B.61⟩ gives the change in deposits as a function of the respective bond price changes,

$$\mathsf{d}D^{NB} = -P_S\left(\frac{\partial f_S^{NB}}{\partial P_S}\mathsf{d}P_S + \frac{\partial f_S^{NB}}{\partial P_L}\mathsf{d}P_L\right) - P_L\left(\frac{\partial f_L^{NB}}{\partial P_S}\mathsf{d}P_S + \frac{\partial f_L^{NB}}{\partial P_L}\mathsf{d}P_L\right), \qquad \langle \text{B.70} \rangle$$

where the arguments of the demand functions have been dropped for notational simplicity.

Banks The balance sheet identity of the banking sector is given by

$$R + P_S B_S^B + P_L B_L^B = E^B + D^B \qquad \langle \text{B.71} \rangle$$

where

$$F^B = E^B + D^B \qquad \langle \text{B.72} \rangle$$

denotes the funding of banks. As argued in the main text, reserves and deposits are assumed to be perfect substitutes. Moreover, banks consider deposits as exogenous and they cannot issue new equity or debt given the short-term nature of the model. Thus, banks' bond demand functions are given by

$$B_S^B = f_S^B(P_S, P_L, F_B), \qquad \langle \text{B.73} \rangle$$

$$B_L^B = f_L^B(P_S, P_L, F_B). \qquad \langle \text{B.74} \rangle$$

Since changes in equity valuations do not affect the bond demand of banks, i.e.

$$\frac{\partial f_S^B(P_S, P_L, F^B)}{\partial F^B}\mathsf{d}E^B = 0 \quad \text{and} \quad \frac{\partial f_L^B(P_S, P_L, F^B)}{\partial F^B}\mathsf{d}E^B = 0, \qquad \langle \text{B.75} \rangle$$

the total derivatives of ⟨B.73⟩ and ⟨B.74⟩ reduce to

$$\mathsf{d}B_S^B = \frac{\partial f_S^B}{\partial P_S}\mathsf{d}P_S + \frac{\partial f_S^B}{\partial P_L}\mathsf{d}P_L + \frac{\partial f_S^B}{\partial F^B}\mathsf{d}D^B, \tag{B.76}$$

$$\mathsf{d}B_L^B = \frac{\partial f_L^B}{\partial P_S}\mathsf{d}P_S + \frac{\partial f_L^B}{\partial P_L}\mathsf{d}P_L + \frac{\partial f_L^B}{\partial F^B}\mathsf{d}D^B, \tag{B.77}$$

where, as above, the arguments of the demand functions have been dropped for notational simplicity. A crucial feature for the existence of the reserve-induced portfolio balance channel is that banks increase their bond demand in response to changes in available funding, thus

$$0 < \frac{\partial f_S^B}{\partial F_B} < 1 \quad \text{and} \quad 0 < \frac{\partial f_L^B}{\partial F_B} < 1. \tag{B.78}$$

Equilibrium Analysis Since the model assumes a constant bond supply, bond market clearing requires that changes in the bond holdings of non-banks, banks, and the central bank sum up to zero, i.e.

$$\mathsf{d}B_S^{NB} + \mathsf{d}B_S^B + \mathsf{d}B_S^{CB} = 0 \tag{B.79}$$

$$\mathsf{d}B_L^{NB} + \mathsf{d}B_L^B + \mathsf{d}B_L^{CB} = 0. \tag{B.80}$$

Assuming that the central bank buys only short-term bonds implies $\mathsf{d}B_S^{CB} > 0$ and $\mathsf{d}B_L^{CB} = 0$. Plugging the latter information as well as equations ⟨B.69⟩ and ⟨B.77⟩ into ⟨B.80⟩ yields the demand for long-term bonds as a function of the relative change in asset prices

$$\mathsf{d}B_L^{NB} + \mathsf{d}B_L^B = \frac{\partial f_L^{NB}}{\partial P_S}\mathsf{d}P_S + \frac{\partial f_L^{NB}}{\partial P_L}\mathsf{d}P_L + \frac{\partial f_L^B}{\partial P_S}\mathsf{d}P_S + \frac{\partial f_L^B}{\partial P_L}\mathsf{d}P_L + \frac{\partial f_L^B}{\partial F^B}\mathsf{d}D^B. \tag{B.81}$$

Given that aggregate changes in bank deposits reflect equivalent changes in the deposit holdings of non-banks, i.e. $\mathsf{d}D^B = \mathsf{d}D^{NB}$, equation ⟨B.70⟩ can be used to substitute out $\mathsf{d}D^B$ in the expression above. After some rearrangements, this gives the market clearing condition for long-term bonds as

$$\mathsf{d}P_S\left(\frac{\partial f_L^{NB}}{\partial P_S} + \frac{\partial f_L^B}{\partial P_S} - \frac{\partial f_L^B}{\partial F^B}\left(P_S\frac{\partial f_S^{NB}}{\partial P_S} + P_L\frac{\partial f_L^{NB}}{\partial P_S}\right)\right)$$

$$+\,\mathsf{d}P_L\left(\frac{\partial f_L^{NB}}{\partial P_L}+\frac{\partial f_L^{B}}{\partial P_L}-\frac{\partial f_L^{B}}{\partial F^B}\left(P_S\frac{\partial f_S^{NB}}{\partial P_L}+P_L\frac{\partial f_L^{NB}}{\partial P_L}\right)\right)=0. \quad \langle\text{B.82}\rangle$$

The same manipulations can be applied to the bond market clearing condition of short-term bonds. Using equations ⟨B.68⟩, ⟨B.76⟩, and ⟨B.70⟩ in equation ⟨B.79⟩ yields, after some rearrangements,

$$\mathsf{d}P_S\left(\frac{\partial f_S^{NB}}{\partial P_S}+\frac{\partial f_S^{B}}{\partial P_S}-\frac{\partial f_S^{B}}{\partial F^B}\left(P_S\frac{\partial f_S^{NB}}{\partial P_S}+P_L\frac{\partial f_L^{NB}}{\partial P_S}\right)\right)$$
$$+\,\mathsf{d}P_L\left(\frac{\partial f_S^{NB}}{\partial P_L}+\frac{\partial f_S^{B}}{\partial P_L}-\frac{\partial f_S^{B}}{\partial F^B}\left(P_S\frac{\partial f_S^{NB}}{\partial P_L}+P_L\frac{\partial f_L^{NB}}{\partial P_L}\right)\right)=-\mathsf{d}B_S^{CB} \quad \langle\text{B.83}\rangle$$

Since the goal is to find the change in bond prices in response to central bank purchases of short-term bonds ($\frac{\mathsf{d}P_L}{\mathsf{d}B_S^{CB}}, \frac{\mathsf{d}P_S}{\mathsf{d}B_S^{CB}}$), using matrix notation, the two clearing conditions ⟨B.82⟩ and ⟨B.83⟩ can be combined to get

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}\begin{bmatrix} \mathsf{d}P_S \\ \mathsf{d}P_L \end{bmatrix}=\begin{bmatrix} 0 \\ -\mathsf{d}B_S^{CB} \end{bmatrix} \quad \langle\text{B.84}\rangle$$

where

$$a_{11}=\frac{\partial f_L^{NB}}{\partial P_S}+\frac{\partial f_L^{B}}{\partial P_S}-\frac{\partial f_L^{B}}{\partial F^B}\left(P_S\frac{\partial f_S^{NB}}{\partial P_S}+P_L\frac{\partial f_L^{NB}}{\partial P_S}\right);$$
$$a_{12}=\frac{\partial f_L^{NB}}{\partial P_L}+\frac{\partial f_L^{B}}{\partial P_L}-\frac{\partial f_L^{B}}{\partial F^B}\left(P_S\frac{\partial f_S^{NB}}{\partial P_L}+P_L\frac{\partial f_L^{NB}}{\partial P_L}\right);$$
$$a_{21}=\frac{\partial f_S^{NB}}{\partial P_S}+\frac{\partial f_S^{B}}{\partial P_S}-\frac{\partial f_S^{B}}{\partial F^B}\left(P_S\frac{\partial f_S^{NB}}{\partial P_S}+P_L\frac{\partial f_L^{NB}}{\partial P_S}\right);$$
$$a_{22}=\frac{\partial f_S^{NB}}{\partial P_L}+\frac{\partial f_S^{B}}{\partial P_L}-\frac{\partial f_S^{B}}{\partial F^B}\left(P_S\frac{\partial f_S^{NB}}{\partial P_L}+P_L\frac{\partial f_L^{NB}}{\partial P_L}\right),$$

Premultiplying equation ⟨B.84⟩ with the inverse of the coefficient matrix gives,

$$\begin{bmatrix} \mathsf{d}P_S \\ \mathsf{d}P_L \end{bmatrix}=\frac{1}{a_{11}a_{22}-a_{21}a_{12}}\begin{bmatrix} a_{22} & -a_{12} \\ -a_{21} & a_{11} \end{bmatrix}\begin{bmatrix} 0 \\ -\mathsf{d}B_S^{CB} \end{bmatrix}, \quad \langle\text{B.85}\rangle$$

with the general results of

$$\frac{\mathsf{d}P_S}{\mathsf{d}B_S^{CB}} = \frac{a_{12}}{a_{11}a_{22} - a_{21}a_{12}} \quad \text{and} \quad \frac{\mathsf{d}P_L}{\mathsf{d}B_S^{CB}} = -\frac{a_{11}}{a_{11}a_{22} - a_{21}a_{12}}. \qquad \langle \text{B.86} \rangle$$

To highlight the intuition behind the reserve-induced channel, in the following it is assumed that $\frac{\partial f_S^{NB}}{\partial P_S} \to \infty$ and $\frac{\partial f_S^B}{\partial P_S} = 0$, implying that the central bank buys short-term bonds only from non-banks. Another implication of the perfect own-price elasticity of short-term bonds is that $\frac{\mathsf{d}P_S}{B_S^{CB}} = 0$. Furthermore, since reserves and short-term bonds are perfect substitutes at the zero lower bound, banks with higher deposits will demand only long-term bonds, thus, $\frac{f_S^B}{F^B} = 0$ and $0 < \frac{f_L^B}{F^B} < 1$. Finally, the cross-price elasticities of bonds are set to zero so that no substitution between short- and long-term bonds is possible.[2] Using all this information in equation ⟨B.86⟩ results in

$$\frac{\mathsf{d}P_L}{\mathsf{d}B_S^{CB}} = \frac{-P_S \frac{\partial f_L^B}{F^B}}{\frac{\partial f_L^{NB}}{\partial P_L} + \frac{\partial f_L^B}{\partial P_L} - P_L \frac{\partial f_L^B}{F^B} \frac{\partial f_L^{NB}}{\partial P_L}} \qquad \langle \text{B.87} \rangle$$

which corresponds to equation ⟨5.36⟩ in the main text.

[2]This assumption is not necessary to obtain the result that central bank purchases of short-term bonds increase the prices of long-term bonds. The necessary condition is only that the cross-price elasticities are smaller than the direct own-price elasticities, which can be reasonably assumed for standard preferences for bond demand.

B.5. A Model of the Bank Lending Channel of LSAPs

Plugging the expected costs of wholesale financing,

$$\frac{\alpha_1}{2}E(WL_1)^2 = \frac{\alpha_1}{6}\left(L - WL_0 - \rho D_0 - (1-\rho)\bar{D} + \frac{\sigma^2}{2} - E_0\right)^2, \qquad \langle B.88\rangle$$

into banks' profit function ⟨7.20⟩,

$$\Pi = rL - \frac{\alpha_0(WL_0)^2}{2} - \frac{\alpha_1 E(WL_1)^2}{2}, \qquad \langle B.89\rangle$$

yields

$$\Pi = rL - \frac{\alpha_0(WL_0)^2}{2} - \frac{\alpha_1}{6}\left(L - WL_0 - \rho D_0 - (1-\rho)\bar{D} + \frac{\sigma^2}{2} - E_0\right)^2. \qquad \langle B.90\rangle$$

Differentiating this expression with respect to loans (L) and wholesale liabilities (WL_0) gives

$$\frac{\partial \Pi}{\partial L} = r - \frac{\alpha_1}{3}\left(L - WL_0 - \rho D_0 - (1-\rho)\bar{D} + \frac{\sigma^2}{2} - E_0\right) = 0, \qquad \langle B.91\rangle$$

$$\frac{\partial \Pi}{\partial WL_0} = -\alpha_0 WL_0 + \frac{\alpha_1}{3}\left(L - WL_0 - \rho D_0 - (1-\rho)\bar{D} + \frac{\sigma^2}{2} - E_0\right) = 0 \qquad \langle B.92\rangle$$

and these two FOCs can be combined to get

$$r - \frac{2\alpha_1}{3}\left(L - WL_0 - \rho D_0 - (1-\rho)\bar{D} + \frac{\sigma^2}{2} - E_0\right) = -\alpha_0 WL_0. \qquad \langle B.93\rangle$$

Furthermore, since the optimality condition ⟨B.91⟩ implies that

$$r = \frac{\alpha_1\left(L - WL_0 - \rho D_0 - (1-\rho)\bar{D} + \frac{\sigma^2}{2} - E_=\right)}{3} \qquad \langle B.94\rangle$$

and ⟨B.92⟩ that

$$WL_0 = \frac{\alpha_1\left(L - WL_0 - \rho D_0 - (1-\rho)\bar{D} + \frac{\sigma^2}{2} - E_0\right)}{3\alpha_0}, \qquad \langle B.95\rangle$$

substituting ⟨B.94⟩ into ⟨B.95⟩ gives

$$WL_1 = \frac{r}{\alpha_1}. \tag{B.96}$$

Plugging this into ⟨B.93⟩ and solving for L yields

$$L = \frac{3}{\alpha_2}r + \frac{r}{\alpha_1} + \rho D_1 + (1-\rho)D - \frac{\sigma^2}{2} + E_1, \tag{B.97}$$

which corresponds to equation ⟨7.21⟩ in the main text.

In a next step, this loan supply function is plugged into equation ⟨7.23⟩, which gives

$$Y - kr = n\left(\frac{3}{\alpha_2}r + \frac{r}{\alpha_1} + \rho D_1 + (1-\rho)D - \frac{\sigma^2}{2} + E_1\right) \tag{B.98}$$

$$\Leftrightarrow Y - n\left(\rho D_1 + (1-\rho)D - \frac{\sigma^2}{2} + E_1\right) = \left(\frac{3n}{\alpha_2} + \frac{n}{\alpha_1} + k\right)r \tag{B.99}$$

$$\Leftrightarrow r = \frac{1}{\frac{3n}{\alpha_2} + \frac{n}{\alpha_1} + k}\left(Y - n\left(\rho D_1 + (1-\rho)D - \frac{\sigma^2}{2} + E_1\right)\right) \tag{B.100}$$

where the last line determining the equilibrium loan rate corresponds to equation ⟨7.24⟩ in the main text.

B.6. DSGE-Model of the Portfolio Balance Effect

Optimization The optimality conditions ⟨8.7⟩, ⟨8.8⟩, ⟨8.9⟩, ⟨8.10⟩, and ⟨8.11⟩ of the main text are derived by setting-up the Lagrangian

$$\begin{aligned}
\mathcal{L} = a_t & \left[\frac{1}{1-\sigma}\left(\frac{C_t}{(C_{t-1})^h}\right)^{1-\sigma} + \frac{1}{1-\delta}\left(\frac{M_t}{e_t P_t}\right)^{1-\delta} - \frac{(N_t)^{1+\varphi}}{1+\varphi}\right] \\
& - \frac{d}{2}\left\{exp\left[c\left(\frac{M_t/P_t}{M_{t-1}/P_{t-1}} - 1\right)\right] + exp\left[-c\left(\frac{M_t/P_t}{M_{t-1}/P_{t-1}} - 1\right)\right] - 2\right\} \\
& + \mathrm{E}_t\beta^t\left\{a_{t+1}\left[\frac{1}{1-\sigma}\left(\frac{C_{t+1}}{(C_t)^h}\right)^{1-\sigma} + \frac{1}{1-\delta}\left(\frac{M_{t+1}}{e_{t+1}P_{t+1}}\right)^{1-\delta} - \frac{(N_{t+1})^{1+\varphi}}{1+\varphi}\right]\right. \\
& \left. - \frac{d}{2}\left\{exp\left[c\left(\frac{M_{t+1}/P_{t+1}}{M_t/P_t} - 1\right)\right] + exp\left[-c\left(\frac{M_{t+1}/P_{t+1}}{M_t/P_t} - 1\right)\right] - 2\right\}\right\} \\
& - \Lambda_t\left[\frac{M_t}{P_t} + \frac{B_t}{P_t i_t} + \frac{B_{L,t}}{P_t i^L_{L,t}} + C_t - \frac{M_{t-1} + B_{t-1} + B_{L,t-L} + W_t N_t + T_t + D_t}{P_t}\right] \\
& - \mathrm{E}_t\beta^t\Lambda_{t+1}\left[\frac{M_{t+1}}{P_{t+1}} + \frac{B_{t+1}}{P_{t+1}i_{t+1}} + \frac{B_{L,t+1}}{P_{t+1}i^L_{L,t+1}} + C_t\right. \\
& \left. - \frac{M_t + B_t + B_{L,t-L+1} + W_{t+1}N_{t+1} + T_{t+1} + D_{t+1}}{P_{t+1}}\right]
\end{aligned} \tag{B.101}$$

and taking the partial derivatives with respect to the choice variables:

$$\frac{\partial\mathcal{L}}{\partial C_t} = a_t U_{t,C_t} + \beta\mathrm{E}_t\left\{a_{t+1}U_{t+1,C_t}\right\} - \Lambda_t = 0 \tag{B.102}$$

$$\frac{\partial\mathcal{L}}{\partial N_t} = -a_t(N_t)^\varphi + \Lambda_t\left(\frac{W_t}{P_t}\right) = 0 \tag{B.103}$$

$$\frac{\partial\mathcal{L}}{\partial B_t} = -\Lambda_t\frac{1}{P_t i_t} + \beta\mathrm{E}_t\frac{\Lambda_{t+1}}{P_{t+1}} = 0 \tag{B.104}$$

$$\frac{\partial\mathcal{L}}{\partial B_{L,t}} = -\Lambda_t\frac{1}{P_t(i_{L,t})^L} + \beta^L\mathrm{E}_t\frac{\Lambda_{t+L}}{P_{t+L}} = 0 \tag{B.105}$$

$$\frac{\partial\mathcal{L}}{\partial M_t} = a_t V_{t,M_t} - \left\{G_{t,M_t} + \beta\mathrm{E}_t\left\{G_{t+1,M_t}\right\}\right\} - \frac{\Lambda_t}{P_t} + \beta\mathrm{E}_t\frac{\Lambda_{t+1}}{P_{t+1}} = 0 \tag{B.106}$$

where

$$U_{t,C_t} = \frac{\partial U_t}{\partial C_t} = \frac{(C_t)^{-\sigma}}{(C_{t-1})^{h-\sigma h}}, \tag{B.107}$$

$$U_{t+1,C_t} = \frac{\partial U_{t+1}}{\partial C_t} = -h\frac{(C_{t+1})^{1-\sigma}}{(C_t)^{1+h-\sigma h}}, \tag{B.108}$$

$$V_{t,M_t} = \frac{\partial V_t}{\partial M_t} = \frac{(M_t)^{-\delta}}{(e_t P_t)^{1-\delta}}, \tag{B.109}$$

$$\begin{aligned} G_{t,M_t} = \frac{\partial G_t}{\partial M_t} = \frac{dc}{2P_t M_{t-1}/P_{t-1}} &\left[exp\left[c\left(\frac{M_t/P_t}{M_{t-1}/P_{t-1}} - 1\right)\right]\right. \\ &\left.-exp\left[-c\left(\frac{M_t/P_t}{M_{t-1}/P_{t-1}} - 1\right)\right]\right] \end{aligned} \tag{B.110}$$

$$\begin{aligned} G_{t+1,M_t} = \frac{\partial G_{t+1}}{\partial M_t} = -\frac{dc(M_{t+1}/P_{t+1})}{2(M_t)^2/P_t} &\left[exp\left[c\left(\frac{M_{t+1}/P_{t+1}}{M_t/P_t} - 1\right)\right]\right. \\ &\left.-exp\left[-c\left(\frac{M_{t+1}/P_{t+1}}{M_t/P_t} - 1\right)\right]\right]. \end{aligned} \tag{B.111}$$

Linearisation Equation ⟨8.7⟩, the FOC for intertemporal consumption can be written as

$$\Lambda_t = a_t C_t^{-\sigma} C_{t-1}^{-h(1-\sigma)} - \beta h C_t^{-h(1-\sigma)-1} \mathrm{E}_t \left\{ a_{t+1} C_{t+1}^{1-\sigma} \right\}. \tag{B.112}$$

or, in functional form, as

$$G(\Lambda_t) = F\left(a_t, a_{t+1}, C_{t-1}, C_t, C_{t+1}\right). \tag{B.113}$$

The steady state value thus equals

$$\begin{aligned} &\Lambda = aC^{-\sigma-h(1-\sigma)} - \beta ha C^{-\sigma-h(1-\sigma)} \\ &\Leftrightarrow \Lambda = aC^{-\sigma-h(1-\sigma)}(1-\beta h). \end{aligned} \tag{B.114}$$

To employ the Taylor approximation method for multivariate functions, i.e. equation ⟨A.12⟩, I start with calculating the respective partials at the steady state:

$$F_{a_t}^{SS} = C^{-\sigma-h(1-\sigma)} \tag{B.115}$$

$$F_{a_t}^{SS} a\hat{a}_t = C^{-\sigma-h(1-\sigma)} a\hat{a}_t \tag{B.116}$$

$$F_{a_{t+1}}^{SS} = -\beta h C^{-\sigma-h(1-\sigma)} \tag{B.117}$$

$$F^{SS}_{a_{t+1}} a\hat{a}_{t+1} = -\beta h C^{-\sigma-h(1-\sigma)} a\hat{a}_{t+1} \tag{B.118}$$

$$F^{SS}_{C_{t-1}} = -h(1-\sigma) a C^{-h(1-\sigma)-1} \tag{B.119}$$

$$F^{SS}_{C_{t-1}} C\hat{c}_{t-1} = -h(1-\sigma) a C^{-h(1-\sigma)} \hat{c}_{t-1} \tag{B.120}$$

$$F^{SS}_{C_t} = -\sigma a C^{-\sigma-1-h(1-\sigma)} - \beta h a(-h(1-\sigma)-1) C^{-h(1-\sigma)-1-\sigma} \tag{B.121}$$

$$F^{SS}_{C_t} C\hat{c}_t = \Big(-\sigma + \beta h^2(1-\sigma) + \beta h\Big) a C^{-\sigma-h(1-\sigma)} \hat{c}_t \tag{B.122}$$

$$F^{SS}_{C_{t+1}} = -\beta h(1-\sigma) C^{-\sigma-h(1-\sigma)-1} \tag{B.123}$$

$$F^{SS}_{C_{t+1}} C\hat{c}_{t+1} = -\beta h(1-\sigma) C^{-\sigma-h(1-\sigma)} \hat{c}_{t+1} \tag{B.124}$$

$$G^{SS}_{\Lambda_t} \Lambda\hat{\Lambda}_t = \Lambda\hat{\Lambda}_t \tag{B.125}$$

Applying ⟨A.12⟩ yields

$$\begin{aligned}\Lambda\hat{\Lambda}_t = {} & C^{-\sigma-h(1-\sigma)} a\hat{a}_t - \beta h C^{-\sigma-h(1-\sigma)} a\hat{a}_{t+1} - h(1-\sigma) a C^{-h(1-\sigma)} \hat{c}_{t-1} \\ & + \Big(-\sigma + \beta h^2(1-\sigma) + \beta h\Big) a C^{-\sigma-h(1-\sigma)} \hat{c}_t - \beta h(1-\sigma) C^{-\sigma-h(1-\sigma)} \hat{c}_{t+1}.\end{aligned} \tag{B.126}$$

Dividing through $\Lambda = aC^{-\sigma-h(1-\sigma)}(1-\beta h)$ and using the market clearing condition $\hat{y}_t = \hat{c}_t$ simplifies the above equation to

$$\begin{aligned}\hat{\Lambda}_t &= \frac{(\sigma-1)h}{1-\beta h}\hat{y}_{t-1} - \frac{\sigma + (\sigma-1)\beta h^2 - \beta h}{1-\beta h}\hat{y}_t + \frac{(\sigma-1)\beta h}{1-\beta h}\hat{y}_{t+1} + \frac{1-\beta h\rho_a}{1-\beta h}\hat{a}_t \\ \Leftrightarrow \hat{\Lambda}_t &= \phi_1\hat{y}_{t-1} - \phi_2\hat{y}_t + \beta\phi_1\hat{y}_{t+1} + \frac{1-\beta h\rho_a}{1-\beta h}\hat{a}_t,\end{aligned} \tag{B.127}$$

with

$$\phi_1 = \frac{(\sigma-1)h}{1-\beta h} \qquad \phi_2 = \frac{\sigma + (\sigma-1)\beta h^2 - \beta h}{1-\beta h},$$

where it was also used that the preference shock $\hat{a}_t$ follows an AR(1)-process of

$$\hat{a}_t = \rho_a \hat{a}_{t-1} \epsilon_{a_t}. \tag{B.128}$$

The FOC for short-term bonds, equation ⟨8.9⟩ in the main text, is a multiplicative function only, which is linearised to

$$\hat{\Lambda}_t = \hat{i}_t - \mathrm{E}_t\hat{\pi}_{t+1} + \mathrm{E}_t\hat{\Lambda}_{t+1}. \tag{B.129}$$

With the Fisher equation

$$\hat{r}_t = \hat{i}_t - \mathrm{E}_t \hat{\pi}_{t+1} \tag{B.130}$$

the nominal interest rate $\hat{i}_t$ and inflation in equation ⟨B.129⟩ is substituted with the real interest rate ($\hat{r}_t$), such that

$$\hat{\Lambda}_t = \hat{r}_t + \mathrm{E}_t \hat{\Lambda}_{t+1}. \tag{B.131}$$

Applying the same procedure to the FOC for long-term bond holdings – equation ⟨8.10⟩ in the main text – results in

$$\hat{\Lambda}_t = L\widehat{r}_{L,t} - \mathrm{E}_t \hat{\pi}_{t+L} + \mathrm{E}_t \hat{\Lambda}_{t+L}. \tag{B.132}$$

where

$$\hat{r}_{L,t} = \hat{i}_{L,t} - \frac{1}{L} \mathrm{E}_t \sum_{j=0}^{L-1} \hat{\pi}_{t+j+1}, \tag{B.133}$$

was used to get

$$\hat{\Lambda}_t = L\hat{r}_{L,t} + \mathrm{E}_t \hat{\Lambda}_{t+L}. \tag{B.134}$$

Combining equation ⟨B.131⟩ and ⟨B.134⟩ gives

$$L\hat{r}_{L,t} = \hat{r}_t + \mathrm{E}_t \Lambda_{t+1} - \mathrm{E}_t \Lambda_{t+L}. \tag{B.135}$$

Finally, iterating forward equation ⟨B.131⟩ for L-periods and plugging this sequence into the above equation, yields

$$\hat{r}_{L,t} = \frac{1}{L} \sum_{j=0}^{L-1} \hat{r}_{t+j} \tag{B.136}$$

representing the expectations theory of the term structure, i.e. equation ⟨8.17⟩ in the main text.

The linearised money demand equation in the case of perfect asset substitutability but with adjustment costs, i.e. equation ⟨8.19⟩ from the main text, is derived from

$$a_t V_{t,M_t^u} - \left\{ G_{t,M_t^u} + \beta \mathrm{E}_t \left\{ G_{t+1,M_t^u} \right\} \right\} = \frac{\Lambda_t^u}{P_t} - \frac{\Lambda_t^u}{i_t P_t}$$
$$= \frac{\Lambda_t}{P_t} \left(1 - \frac{1}{i_t} \right) = \frac{\Lambda_t}{P_t} \left(\frac{i_t - 1}{i_t} \right), \tag{B.137}$$

or,

$$\frac{\Lambda}{P_t}\left(\frac{i_t-1}{i_t}\right)=a_t\frac{(M_t^u)^{-\delta}}{(e_tP_t)^{1-\delta}}-\frac{dc}{2P_tM_{t-1}^u/P_{t-1}}\left\{exp\left[c\left(\frac{M_t^u/P_t}{M_{t-1}^u/P_{t-1}}-1\right)\right]\right.$$
$$\left.-exp\left[-c\left(\frac{M_t^u/P_t}{M_{t-1}^u/P_{t-1}}-1\right)\right]\right\}+\beta\frac{dc(M_{t+1}^u/P_{t+1})}{2(M_t^u)^2/P_t}$$
$$\left\{exp\left[c\left(\frac{M_{t+1}^u/P_{t+1}}{M_t^u/P_t}-1\right)\right]-exp\left[-c\left(\frac{M_{t+1}^u/P_{t+1}}{M_t^u/P_t}-1\right)\right]\right\}. \quad \langle B.138\rangle$$

Multiplying with P_t and expressing the above equation in real terms yields

$$\Lambda_t-\Lambda_tr_t^{-1}=a_te_t^{\delta-1}m_t^{-\delta}$$
$$-\frac{d}{2}cm_{t-1}^{-1}\left\{exp\left[c\left(m_tm_{t-1}^{-1}-1\right)\right]-exp\left[-c\left(m_tm_{t-1}^{-1}-1\right)\right]\right\}$$
$$+\beta\frac{d}{2}cm_{t+1}m_t^{-1}\left\{\left[c\left(m_{t+1}m_t^{-1}-1\right)\right]-exp\left[-c\left(m_{t+1}m_t^{-1}-1\right)\right]\right\}, \quad \langle B.139\rangle$$

which, in functional form, is given by

$$G(\Lambda_t,i_t)=F\left(a_t,e_t,m_{t-1},m_t,m_{t+1}\right). \quad \langle B.140\rangle$$

Again, this multivariate expression is linearised by applying the Taylor approximation method of equation ⟨A.2⟩. In a first step, I compute the respective partials

$$G_{\Lambda_t}^{SS}\Lambda\hat{\Lambda}_t=i^{-1}(i-1)\Lambda\hat{\Lambda}_t \quad \langle B.141\rangle$$

$$G_{i_t}^{SS}i\hat{i}_t=\Lambda i^{-1}\hat{i}_t \quad \langle B.142\rangle$$

$$F_{a_t}^{SS}a\hat{a}_t=m^{-\delta}\hat{a}_t \quad \langle B.143\rangle$$

$$F_{e_t}^{SS}e\hat{e}_t=-(1-\delta)m^{-\delta}\hat{e}_t \quad \langle B.144\rangle$$

$$F_{m_{t-1}}^{SS}m\hat{m}_{t-1}=dc^2m^{-1}\hat{m}_{t-1} \quad \langle B.145\rangle$$

$$F_{m_t}^{SS}m\hat{m}_t=-\left(\delta m^{-\delta}+(1+\beta)dc^2m^{-1}\right)\hat{m}_t \quad \langle B.146\rangle$$

$$F_{m_{t+1}}^{SS}m\hat{m}_{t+1}=\beta dc^2m^{-1}\hat{m}_{t+1} \quad \langle B.147\rangle$$

which can be put together to get

$$i^{-1}(i-1)\Lambda\hat{\Lambda}_t + \Lambda i^{-1}\hat{i}_t = m^{-\delta}\hat{a}_t - (1-\delta)m^{-\delta}\hat{e}_t + dc^2m^{-1}\hat{m}_{t-1}$$
$$- \left(\delta m^{-\delta} + (1+\beta)dc^2m^{-1}\right)\hat{m}_t + \beta dc^2m^{-1}\hat{m}_{t+1}. \quad \langle B.148\rangle$$

Using $\Lambda = \frac{i}{m^{-\delta}(i-1)}$ and multiplying both sides with δ^{-1} and m^{δ} results in

$$\delta^{-1}m^{\delta}i^{-1}(i-1)\Lambda\hat{\Lambda}_t + \delta^{-1}m^{\delta}\Lambda i^{-1}\hat{i}_t = \delta^{-1}\hat{a}_t - (1-\delta)\delta^{-1}\hat{e}_t + dc^2m^{\delta}m^{-1}\delta^{-1}\hat{m}_{t-1}$$
$$- \left(1 + (1+\beta)dc^2\delta^{-1}m^{\delta-1}\right)\hat{m}_t + \beta dc^2\delta^{-1}m^{\delta-1}\hat{m}_{t+1} \quad \langle B.149\rangle$$

This can be simplified to

$$(1+(1+\beta)\delta_0)\,\hat{m}_t = \delta^{-1}\hat{a}_t + (\delta-1)\delta^{-1}\hat{e}_t$$
$$+ \delta_0\hat{m}_{t-1} + \beta\delta_0\hat{m}_{t+1} - \delta^{-1}\hat{\Lambda}_t - \delta^{-1}(i-1)^{-1}\hat{i}_t \quad \langle B.150\rangle$$

where

$$\delta_0 = dc^2\delta^{-1}m^{\delta-1}.$$

The linearised money demand equation can thus be written as

$$\hat{m}_t = \frac{\delta_0}{1+\delta_0(1+\beta)}\hat{m}_{t-1} + \frac{\beta\delta_0}{1+\delta_0(1+\beta)} - \frac{1}{\delta(1+\delta_0(1+\beta))}(\hat{\Lambda}_t - \hat{a}_t)$$
$$- \frac{1}{\delta(i-1)(1+\delta_0(1+\beta))}\hat{i}_t + \frac{\delta-1}{\delta(1+\delta_0(1+\beta))}\hat{e}_t$$
$$= \mu_1\hat{m}_{t-1} + \beta\mu_1\hat{m}_{t+1} - \mu_3(\hat{\Lambda}_t - \hat{a}_t) - \mu_4\hat{i}_t + \mu_5\hat{e}_t \quad \langle B.151\rangle$$

which corresponds to equation ⟨8.19⟩ in the main text.

Under imperfect asset substitutability, real money demand – equation ⟨8.26⟩ of the main text – is obtained by linearising equation ⟨8.23⟩ around the steady state. Rewriting the latter in real terms yields

$$\Lambda_t - \Lambda_t i_t^{-1} = a_t e_t^{\delta-1}m_t^{-\delta} - \upsilon\kappa b_{L,t}^{-1}\left[m_t b_{L,t}^{-1}\kappa - 1\right]$$

$$- \frac{d}{2} c m_{t-1}^{-1} \left\{ exp \left[c \left(m_t m_{t-1}^{-1} - 1 \right) \right] - exp \left[-c \left(m_t m_{t-1}^{-1} - 1 \right) \right] \right\}$$

$$+ \beta \frac{d}{2} c m_{t+1} m_t^{-1} \left\{ \left[c \left(m_{t+1} m_t^{-1} - 1 \right) \right] - exp \left[-c \left(m_{t+1} m_t^{-1} - 1 \right) \right] \right\} \quad \langle B.152 \rangle$$

The sole difference to the baseline case is that long-term bonds appear as an argument in household's real money demand. In functional, this is given by

$$G(\Lambda_t, i_t) = F\left(a_t, e_t, m_{t-1}, m_t, m_{t+1}, b_{L,t}\right). \quad \langle B.153 \rangle$$

The partials are the same as in the baseline case as well, except for

$$F_{m_t}^{SS} m \hat{m}_t = -\left(\delta m^{-\delta} + (1+\beta) d c^2 m^{-1} + \upsilon m^{-1} \right) \hat{m}_t \quad \langle B.154 \rangle$$

$$F_{b_{L,t}}^{SS} b \hat{b}_{L,t} = \upsilon m^{-1} \hat{b}_{L,t}. \quad \langle B.155 \rangle$$

Using the linearisation formula ⟨A.12⟩ gives

$$\hat{m}_t = \mu_1 \hat{m}_{t-1} + \mu_2 \hat{m}_{t+1} - \mu_3 (\hat{\Lambda}_t - \hat{a}_t) - \mu_4 \hat{i}_t$$
$$+ \mu_5 \hat{e}_t - \frac{\upsilon m^{\delta-1}}{\delta(1+\delta_0(1+\beta))} (\hat{m}_t - \hat{b}_{L,t}) \quad \langle B.156 \rangle$$

with

$$\delta_0 = d c^2 \delta^{-1} m^{\delta-1}, \quad \mu_1 = \frac{\delta_0}{1+\delta_0(1+\beta)}, \quad \mu_2 = \beta \mu_1, \quad \mu_3 = \frac{1}{\delta(1+\delta_0(1+\beta))},$$
$$\mu_4 = \frac{1}{\delta(i-1)(1+\delta_0(1+\beta))}, \quad \mu_5 = \frac{\delta-1}{\delta(1+\delta_0(1+\beta))},$$

which corresponds to equation ⟨8.26⟩ of the main text.[3]

Last but not least, the term structure under imperfect asset substitutability – equation ⟨8.29⟩ of the main text – is derived by firstly multiplying equation ⟨8.24⟩ with P_t and writing it in real terms to get

$$-\upsilon \eta m_t b_{L,t}^{-2} \left[m_t b_{L,t}^{-1} \eta - 1 \right] + \frac{1+\varsigma_t}{(i_L)^L} \Lambda_t = \beta^L \mathrm{E}_t \Lambda_{t+L} \left(\frac{P_t}{P_{t+L}} \right) = \beta^L \mathrm{E}_t \Lambda_{t+L} \pi_{t+L}^{-1}. \quad \langle B.157 \rangle$$

[3]The coefficient μ_5 and the last coefficient, $\frac{\upsilon m^{\delta-1}}{\delta(1+\delta_0(1+\beta))}$, vary slightly from the ones in Andrés et al. (2004). However, my calculations are confirmed by Jones and Kulish (2013), who also apply the model of Andrés et al. (2004).

This can be rearranged to

$$(1+\varsigma_t)\Lambda_t = \Lambda + \varsigma_t\Lambda = (i_L)^L\beta^L \mathrm{E}_t\Lambda_{t+L}\pi_{t+L}^{-1} + (i_L)^L \upsilon\eta m_t b_{L,t}^{-2}\left[m_t b_{L,t}^{-1}\eta - 1\right]. \quad \langle B.158\rangle$$

Expressing the above equation in functional form

$$G(\Lambda_t, \varsigma_t) = F(i_L, \Lambda_{t+L}, \pi_{t+L}, m_t, b_{L,t}) \quad \langle B.159\rangle$$

and applying the Taylor approximation ⟨A.12⟩, results in

$$G_{\Lambda_t}^{SS}\Lambda\hat{\Lambda}_t = \Lambda\hat{\Lambda}_t \quad \langle B.160\rangle$$

$$G_{\varsigma_t}^{SS}\varsigma\hat{\varsigma}_t = \Lambda\varsigma\hat{\varsigma}_t = \Lambda\varsigma_t \quad \text{since} \quad \varsigma\hat{\varsigma}_t \equiv \varsigma_t \quad \langle B.161\rangle$$

$$F_{\Lambda_{t+L}}^{SS}\Lambda \mathrm{E}_t\hat{\Lambda}_{t+L} = \Lambda \mathrm{E}_t\hat{\Lambda}_{t+L} \quad \langle B.162\rangle$$

$$F_{\pi_{t+L}}^{SS}\pi \mathrm{E}_t\hat{\pi}_{t+L} = -\Lambda \mathrm{E}_t\hat{\pi}_{t+L} \quad \langle B.163\rangle$$

$$F_{m_t}^{SS} m\hat{m}_t = (i_L)^L \upsilon b_L^{-1}\hat{m}_t \quad \langle B.164\rangle$$

$$F_{b_{L,t}}^{SS} b\hat{b}_{L,t} = -(i_L)^L \upsilon b_L^{-1}\hat{b}_{L,t}. \quad \langle B.165\rangle$$

Assembling the partials and simplifying the expression yields

$$\begin{aligned}\hat{\Lambda}_t &= L\hat{i}_{L,t} - \mathrm{E}_t\hat{\pi}_{t+L} + \mathrm{E}_t\hat{\Lambda}_{t+L} - \varsigma_t + \tau\left(\hat{m}_t - \hat{b}_{L,t}\right) \\ &= L\hat{r}_{L,t} + \mathrm{E}_t\hat{\Lambda}_{t+L} - \varsigma_t + \tau\left(\hat{m}_t - \hat{b}_{L,t}\right) \quad \langle B.166\rangle\end{aligned}$$

where

$$\tau = \frac{\upsilon(i_L)^L(i-1)}{b_L m^{-\delta} i} \quad \langle B.167\rangle$$

Equation ⟨8.13⟩

$$\hat{\Lambda}_t = \hat{r}_t + \mathrm{E}_t\hat{\Lambda}_{t+1}. \quad \langle B.168\rangle$$

can be used to substitute out $\hat{\Lambda}_t$ (and subsequently $\hat{\Lambda}_{t+j}$) in equation ⟨B.166⟩. Solving this expression leads to

$$\hat{r}_{L,t} = \frac{1}{L}\sum_{j=0}^{L-1}\hat{r}_{t+j} + \frac{1}{L}\left(\varsigma_t - \tau(\hat{m}_t - \hat{b}_{L,t})\right) \quad \langle B.169\rangle$$

which mirrors equation ⟨8.29⟩ of the main text. This expression can be further rearranged to

$$\hat{m}_t - \hat{b}_{L,t} = -\frac{\upsilon(i_L)^L(i-1)}{b_L m^{-\delta} i}\left[L\hat{r}_{L,t} - \sum_{j=0}^{L-1}\hat{r}_{t+j} - \varsigma_t\right], \quad \langle B.170\rangle$$

which can be plugged into ⟨B.156⟩ to get equation ⟨8.31⟩ of the main text as

$$\hat{m}_t = \mu_1\hat{m}_{t-1} + \mu_2\hat{m}_{t+1} - \mu_3(\hat{\Lambda}_t - \hat{a}_t) - \mu_4\hat{i}_t + \mu_5\hat{e}_t + \mu_6\left(L\hat{r}_{L,t} - \sum_{j=0}^{L-1}\hat{r}_{t+j} - \varsigma_t\right) \quad \langle B.171\rangle$$

with

$$\mu_6 = \frac{i}{i-1}\frac{\eta}{(i_L)^L\delta(1+\delta_0(1+\beta))}.$$

B.6.1. ZLB and Financial Intermediaries

Household Optimization The optimization problem of the representative household is

$$\max E \sum_{t=0}^{\infty} \beta^t a_t \left[\frac{(C_t)^{1-\sigma}}{1-\sigma} + \frac{1}{1-\delta} \left(\frac{M_t}{P_t} \right)^{1-\delta} - \frac{(N_t)^{1+\varphi}}{1+\varphi} \right] \tag{B.172}$$

subject to

$$A_t + M_t + P_t C_t \leq i^A_{t-1} A_{t-1} + M_{t-1} + W_t N_t + T_t + D_t \tag{B.173}$$

where i^A_t denote the interest rate that households receive on their bank deposits (A_t) and the remaining variables are defined as in section 8.1 of the main text. Setting up the Lagrangian gives

$$\begin{aligned}
\mathcal{L} = & a_t \left[\frac{(C_t)^{1-\sigma}}{1-\sigma} + \frac{1}{1-\delta} \left(\frac{M_t}{P_t} \right)^{1-\delta} - \frac{(N_t)^{1+\varphi}}{1+\varphi} \right] \\
& + E_t \beta^t a_{t+1} \left[\frac{(C_{t+1})^{1-\sigma}}{1-\sigma} + \frac{1}{1-\delta} \left(\frac{M_{t+1}}{P_{t+1}} \right)^{1-\delta} - \frac{(N_{t+1})^{1+\varphi}}{1+\varphi} \right] \\
& - \lambda_t \left[A_t + M_t + P_t C_t - i^A_{t-1} A_{t-1} - M_{t-1} - W_t N_t - T_t - D_t \right] \\
& - E_t \beta^t \lambda_{t+1} \left[A_{t+1} + M_{t+1} + P_{t+1} C_{t+1} - i^A_t A_t - M_t - W_{t+1} N_{t+1} - T_{t+1} - D_{t+1} \right]
\end{aligned}$$

and taking the partial derivatives with respect to the choice variables:

$$\frac{\partial \mathcal{L}}{\partial C_t} = \frac{a_t (C_t)^{-\sigma}}{P_t} = \lambda_t \tag{B.174}$$

$$\frac{\partial \mathcal{L}}{\partial N_t} = \frac{a_t (N_t)^{\varphi}}{W_t} = \lambda_t \tag{B.175}$$

$$\frac{\partial \mathcal{L}}{\partial M_t} = \frac{a_t}{P_t} \frac{M_t}{P_t}^{-\delta} + \beta E_t \lambda_{t+1} = \lambda_t \tag{B.176}$$

$$\frac{\partial \mathcal{L}}{\partial A_t} = \beta i^A_t E_t \lambda_{t+1} = \lambda_t \tag{B.177}$$

Substituting λ_t (respectively λ_{t+1}) from equation ⟨B.174⟩ into ⟨B.176⟩ yields the Euler equation for consumption:

$$\beta i^A_t E_t \frac{a_{t+1} (C_{t+1})^{-\sigma}}{P_{t+1}} = \frac{a_t (C_t)^{-\sigma}}{P_t}. \tag{B.178}$$

Linearization With $\pi_t \equiv \frac{P_t}{P_{t-1}}$, $r_t^n \equiv -E_t\left(\hat{a}_{t+1} - \hat{a}_t\right)$, and the market clearing condition $\hat{c}_t = \hat{y}_t$, this can be log-linearized to

$$\hat{y}_t = E_t \hat{y}_{t+1} - \frac{1}{\sigma}\left(\hat{i}_t^A - E_t \hat{\pi}_{t+1} - r_t^n\right), \tag{B.179}$$

is is similar to equation ⟨8.74⟩ in the main text. Combining equation ⟨B.174⟩ with ⟨B.175⟩, and noting that $w_t = \frac{W_t}{P_t}$, the intratemporal labor supply condition can be log-linearized to

$$\hat{w}_t = \varphi \hat{n}_t + \sigma \hat{c}_t. \tag{B.180}$$

With $m_t = \frac{M_t}{P_t}$, real money demand follows from substituting equation ⟨B.174⟩ (and its forward iteration for λ_{t+1}) into ⟨B.176⟩, which can be simplified to

$$(m_t)^{-\delta} = (C_t)^{-\sigma} - \beta E_t \pi_{t+1}^{-1} \frac{a_{t+1}}{a_t} C_{t+1}^{-\sigma}. \tag{B.181}$$

Note from equation ⟨B.178⟩ that

$$\beta E_t \pi_{t+1}^{-1} \frac{a_{t+1}}{a_t} C_{t+1}^{-\sigma} = \frac{(C_t)^{-\sigma}}{i_t^A} \tag{B.182}$$

which can be used for the last term in equation ⟨B.181⟩, such that

$$(m_t)^{-\delta} = (C_t)^{-\sigma}\left(1 - \frac{1}{i_t^A}\right). \tag{B.183}$$

With $\hat{c}_t = \hat{y}_t$ this can be log-linearized to

$$\hat{m}_t = \frac{\sigma}{\delta}\hat{y}_t - \frac{1}{\delta}\hat{i}_t^A \tag{B.184}$$

Firm Optimization Firms set prices subject to the Calvo pricing constraint. The optimization is thus similar to the baseline NK model of section 3.1 such that the linearized Phillips curve equals

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \kappa \hat{y}_t \tag{B.185}$$

Financial Intermediary Optimization As discussed in the main text, financial intermediaries maximize

$$\max E_t\left[i_t B_t + i_{L,t+1} B_{L,t} - \left(i_t^A A_t + \frac{\tilde{\upsilon}}{2}\left(\frac{B_t}{B_{L,t}}\tilde{\eta} - 1\right)^2 P_t\right)\right] \tag{B.186}$$

subject to

$$A_t \equiv B_t + B_{L,t}. \tag{B.187}$$

With lower case letters denoting real variables, the maximization problem can be represented as

$$\max E_t \left[i_t b_t + i_{L,t+1} b_{L,t} - \left(i_t^A \left(b_t + b_{L,t} \right) + \frac{\tilde{\upsilon}}{2} \left(\frac{b_t}{b_{L,t}} \tilde{\eta} - 1 \right)^2 \right) \right] \tag{B.188}$$

and the FOCs are thus given by

$$\frac{\partial (.)}{\partial b_t} : i_t - i_t^A - \tilde{\upsilon} \left(\frac{b_t}{b_{L,t}} \tilde{\eta} - 1 \right) \frac{\tilde{\eta}}{b_{L,t}} = 0 \tag{B.189}$$

$$\frac{\partial (.)}{\partial b_{L,t}} : i_{L,t+1} - i_t^A + \tilde{\upsilon} \left(\frac{b_t}{b_{L,t}} \tilde{\eta} - 1 \right) \frac{b_t \tilde{\eta}}{b_{L,t}^2} = 0 \tag{B.190}$$

Linearization The FOC for short-term bonds (long-term bonds) in functional form is given by

$$F(i_t, i_t^A, b_t, b_{L,t}), \tag{B.191}$$

$$G(i_{L,t+1}, i_t^A, b_t, b_{L,t}). \tag{B.192}$$

In line with the Taylor approximation method from equation ⟨A.12⟩, the partials, with $\tilde{\eta} = \frac{b_L}{b}$ and $i = \frac{1}{\beta}$, are computed as

$$F_{i_t}^{SS} i \hat{i}_t = i \hat{i}_t \tag{B.193}$$

$$F_{i_t^A}^{SS} i \hat{i}_t^A = i \hat{i}_t^A \tag{B.194}$$

$$F_{b_t}^{SS} b \hat{b}_t = -\frac{\tilde{\upsilon}}{b} \hat{b}_t \tag{B.195}$$

$$F_{b_{L,t}}^{SS} b \hat{b}_{L,t} = \frac{\tilde{\upsilon}}{b} \hat{b}_{L,t} \tag{B.196}$$

which are put together to yield the linearized optimality condition for short-term bonds:

$$\hat{i}_t^A = \hat{i}_t - \frac{\beta \tilde{\upsilon}}{b} \left(\hat{b}_t - \hat{b}_{L,t} \right) \tag{B.197}$$

For long-term bonds, this is

$$G^{SS}_{i_{L,t}} i\hat{i}_{L,t+1} = i\hat{i}_{L,t+1} \tag{B.198}$$

$$G^{SS}_{i^A_t} i\hat{i}^A_t = i\hat{i}^A_t \tag{B.199}$$

$$G^{SS}_{b_t} b\hat{b}_t = \frac{\tilde{\upsilon}}{b_L}\hat{b}_t \tag{B.200}$$

$$G^{SS}_{b_{L,t}} b\hat{b}_{L,t} = -\frac{\tilde{\upsilon}}{b_L}\hat{b}_{L,t}, \tag{B.201}$$

respectively

$$\hat{i}^A_t = \hat{i}_{L,t+1} + \frac{\beta\tilde{\upsilon}}{b_L}\left(\hat{b}_t - \hat{b}_{L,t}\right). \tag{B.202}$$

Expanding equation ⟨B.202⟩ with $\tilde{\eta}$ results in

$$\tilde{\eta}\hat{i}^A_t = \tilde{\eta}\hat{i}_{L,t+1} + \frac{\tilde{\eta}\beta\tilde{\upsilon}}{b_L}\left(\hat{b}_t - \hat{b}_{L,t}\right) = \tilde{\eta}\hat{i}_{L,t+1} + \frac{\beta\tilde{\upsilon}}{b}\left(\hat{b}_t - \hat{b}_{L,t}\right) \tag{B.203}$$

which can be combined with equation ⟨B.197⟩ to express the deposit rate as

$$\hat{i}^A_t = \frac{1}{1+\tilde{\eta}}\hat{i}_t + \frac{\tilde{\eta}}{1+\tilde{\eta}}\hat{i}_{L,t+1}. \tag{B.204}$$

This corresponds to equation ⟨8.73⟩ of the main text. Finally, setting ⟨B.197⟩ equal to equation ⟨B.202⟩ and solving for $\hat{i}_t$

$$\begin{aligned}
\hat{i}_t - \frac{\beta\tilde{\upsilon}}{b}\left(\hat{b}_t - \hat{b}_{L,t}\right) &= \hat{i}_{L,t+1} + \frac{\beta\tilde{\upsilon}}{b_L}\left(\hat{b}_t - \hat{b}_{L,t}\right) \\
\Leftrightarrow \hat{i}_t &= \hat{i}_{L,t+1} + \frac{\beta\tilde{\upsilon}}{b_L}\left(\hat{b}_t - \hat{b}_{L,t}\right) + \frac{\beta\tilde{\upsilon}}{b}\left(\hat{b}_t - \hat{b}_{L,t}\right) \\
\Leftrightarrow \hat{i}_t &= \hat{i}_{L,t+1} + \left(\hat{b}_t - \hat{b}_{L,t}\right)\left[\frac{\beta\tilde{\upsilon}}{b_L} + \frac{\beta\tilde{\upsilon}}{b}\right] \\
\Leftrightarrow \hat{i}_t &= \hat{i}_{L,t+1} + \left(\hat{b}_t - \hat{b}_{L,t}\right)\left[\frac{\beta\tilde{\upsilon}}{b_L} + \frac{\beta\tilde{\upsilon}\tilde{\eta}}{b_L}\right] \\
\Leftrightarrow \hat{i}_t &= \hat{i}_{L,t+1} + \frac{\beta\tilde{\upsilon}(1+\tilde{\eta})}{b_L}\left(\hat{b}_t - \hat{b}_{L,t}\right) \qquad \text{(B.205)}
\end{aligned}$$

yields equation ⟨8.72⟩ from the main text.

Government The consolidated budget constraint of the government is given by

$$\frac{B^g_{L,t} + B_t - R_{L,t}B_{L,t-1} - R_{t-1}B_{t-1} + \Delta_t}{P_t} = \frac{T_t}{P_t} \qquad \langle B.206\rangle$$

with

$$\frac{\Delta_t}{P_t} = \frac{M_t - M_{t-1}}{P_t} - \left[\frac{B^{CB}_t}{P_t} - \frac{R_{L,t}B^{CB}_{t-1}}{P_t}\right] \qquad \langle B.207\rangle$$

and

$$B^{CB}_t = q_t B^g_{L,t}. \qquad \langle B.208\rangle$$

Inserting equations and defining lower case latter to be real variables (and $\tau_t = \frac{T_t}{P_t}$), yields

$$b_t + m_t + (1-q_t)b^g_{L,t} = \left[m_{t-1} + i_{t-1}b_{t-1} + i_{L,t}(1-q_{t-1})b^g_{L,t-1}\right]\pi_t^{-1} + \tau_t. \qquad \langle B.209\rangle$$

with the bond market clearing condition

$$b_{L,t} = (1-q_t)b^g_{L,t} = (1-q_t)\bar{b}_C V_t \qquad \langle B.210\rangle$$

Linearization The fiscal rule is defined as

$$\frac{\tau}{b}\hat{\tau}_t = -\varkappa\hat{b}_{t-1} - \beta^{-1}\hat{i}_{t-1} \qquad \langle B.211\rangle$$

and the linearized bond market condition equals

$$\hat{b}_{L,t} = -q_t + \hat{V}_t \qquad \langle B.212\rangle$$

where a linear rather than log-linear approximation is applied to q_t since the steady state value of q equals zero. With $i = i_L = \beta^{-1}$ a Taylor series approximation of equation ⟨B.209⟩ gives

$$b\hat{b}_t + m\hat{m}_t + b_L(\hat{V}_t - q_t) = m\hat{m}_{t-1} + \frac{b}{\beta}\hat{i}_{t-1} + \frac{b}{\beta}\hat{b}_{t-1} + \frac{b_L}{\beta}(\hat{V}_{t-1} - q_{t-1})$$
$$+ \frac{b_L}{\beta}\hat{i}_{L,t} - \left[m + \frac{b}{\beta} + \frac{b_L}{\beta}\right]\hat{\pi}_t - b\varkappa\hat{b}_{t-1} - \frac{b}{\beta}\hat{i}_{t-1}. \qquad \langle B.213\rangle$$

For $\tilde{\eta} = \frac{b_L}{b}$ and

$$\begin{aligned} i_{L,t} &= \frac{1+V_t}{V_{t-1}} \\ \Leftrightarrow V i \hat{i}_{L,t} + V i \hat{V}_{t-1} &= V \hat{V}_t \\ \Leftrightarrow \hat{i}_{L,t} &= \beta \hat{V}_t - \hat{V}_{t-1} \end{aligned} \quad \langle \text{B.214} \rangle$$

this can be simplified to

$$\hat{b}_t + \frac{m}{b}\hat{m}_t - q_t\tilde{\eta} = \frac{m}{b}\hat{m}_{t-1} + \left(\frac{1}{\beta} - \varkappa\right)\hat{b}_{t-1} - \frac{\tilde{\eta}}{\beta}q_{t-1} - \left(\frac{m}{b} + \frac{1+\tilde{\eta}}{\beta}\right)\hat{\pi}_t \quad \langle \text{B.215} \rangle$$

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